

POTASH

J. W. TURRENTINE



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EDITED BY

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OF NEW JERSEY

POTASH

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POTASH

A REVIEW, ESTIMATE AND FORECAST

BY

J. W. TURRENTINE, PH.D.

*In Charge, Potash Investigations, Bureau of Soils,
U. S. Department of Agriculture*

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PREFACE

THE ambition and determination to render America independent of foreign countries in respect to her potash supplies resulted immediately upon the realization of that dependence. It required the hard-fisted methods of the former German monarchy as applied to American importers of German potash to bring home to us the absoluteness of our dependence on Germany for all of our potash. There being no other foreign source to which to turn, the natural reaction was that we should take stock of our own raw materials to see if therefrom it was not possible to develop a domestic potash industry. This resolve found point in 1910 when the Government's surveys of American raw materials for potash manufacture were inaugurated.

Compounds of potash for the most part being soluble, this material was looked for among the natural brines and the products of the desiccation of brines. Thorough surveys were accordingly made of salt deposits, brines from salt and oil wells, saline lakes and salt crusts and deposits of salines from desiccated desert lakes. Potash minerals were located and explored. The great, potash-bearing seaweeds of the Pacific were surveyed and their quantity determined. Industrial wastes were examined and measured.

The value of these surveys to America cannot be measured in ordinary units. They have a value greatly in excess of the millions of dollars' worth of potash subsequently produced and directly attributable thereto. It was the threat of the late German Empire that, because of the potash monopoly which it held, the world could be subjected at

its will to potash starvation and be forced to yield to its dictation. This challenge was met in America by the prompt development of practically all of the sources of potash already surveyed by governmental agencies and the establishment of potash manufactories which made America, for the time being, independent of all foreign potash. The effect on the outcome of the world-wide imbroglio of this show of spirited aggressiveness on the part of America cannot be determined, as its value is inestimable.

Under the impetus of that period a relatively enormous amount of work was done both by governmental and private agencies on the technology of extracting potash from the American raw materials. The results, judged as a whole, were exceedingly good.

It is now imperative that the results arrived at during this period be made a matter of permanent record, that the processes developed be preserved for future use, that they be analyzed in terms of normal conditions, that the fallacies be discarded and the elements that are technically and economically sound be made the basis of further research whereon to build processes that are applicable under normal conditions of supply, demand, and competition. Only in this way, now that the actual commercial production of potash from most of these sources has been abandoned, can the great expenditure of skill, energy, and materials in war-time potash production be made to yield profit for future years.

Such considerations as the foregoing have influenced the choice of subjects and the direction of discussions in the following pages, reflecting admiration for the work that has been done and faith and confidence in the ultimate, successful exploitation of America's resources in potash.

J. W. TURRENTINE.

WASHINGTON, January 15, 1926.

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POTASH

FORMER SOURCES OF POTASH

THE discovery of the immense natural subterranean deposits of potash salts in Germany, as a result of the German search for salt, made available for agriculture, for the first time, large quantities of potash at a low price, to take the place of the haphazard quantities formerly applied to the soil as natural ingredients of stable manure and other natural ammoniates and as wood and kelp ash.

It should not be understood from this that the agricultural world was anxiously awaiting the discovery of such a deposit to fulfill a long-felt want of agriculture. On the contrary, unenlightened agriculture was quite content with the potash supplies at hand and in fact attached little importance thereto; but the Germans, desiring to find some use for a material which at that time was largely without use or value, turned to agriculture as the only industry large enough to absorb a heavy tonnage. Scientific data were easily gotten to support the thesis that potash was a valuable plant food: the case was soon thoroughly well established scientifically. The agricultural scientists of many nations have now added their corroboration with many crops and over relatively long periods of years. But the fact remains that the present widespread use of potash resulted not from the demand of agriculture for potash fertilizers, but from the German industrialists' demand for a market. The desire to sell, antedated the desire to use, potash. The development of the potash industry was

accompanied by a well-organized and effective world-wide propaganda to introduce and to increase the use of potash in agriculture. Germany, possessing the world monopoly of that commodity, made the most of her opportunity to develop the highly profitable commercial aspects of that natural advantage. Under her tutelage, ably abetted by the American teacher of farm practice, fertilizer manufacturer, and salesman, the use of potash was rapidly introduced in American agriculture and soon became established as an essential feature of fertilizer practice. It has come to be regarded as an essential ingredient of mixed fertilizers. The area over which it is used has rapidly spread. Its use alone and in heavy applications on special crops is becoming increasingly conventional. This great German enterprise, like the Chilean nitrate industry, has been of world-wide benefit.

IMPORTATIONS OF EUROPEAN POTASH

The consumption of potash in American agriculture closely coincides with importations, since the bulk of the potash imported is used in the fertilizer industry. All of the low-grade salts enter fertilizers.

The importations of European potash for a ten-year period and the range in prices are shown in the following tables. The period 1913-22 is chosen to show the decline in imports due to the war-time embargo on German potash and the recovery realized when that embargo was lifted, and likewise because it was the period during which the American potash industry had its rise and decline. Tables are presented to show the importations of the various potash salts and prices and likewise the total importations.

With the termination of the war, the return to France of Alsace with her rich and important potash mines apparently broke the German monopoly. France immediately placed these mines under governmental operation and entered the world market with Alsatian potash. Inasmuch

as the American market was divided in the proportion of $62\frac{1}{2}$ per cent to the Germans and $37\frac{1}{2}$ per cent to the French, it may be assumed that the post-war importation from the respective producing countries was resumed approximately on the basis of that ratio.

Considerable confusion arises from the somewhat illogical use of the word "potash" now imposed by convention. To the lay mind, potash is potash, whether it be in the form of 12 per cent German kainite or of 98 per cent American muriate. But in reporting results of analysis of potash carriers and in quoting prices of potash salts, it is evident that some standard basis of computation must be adopted. The 12 per cent and the 50 per cent salts cannot be sold at the same price. The standard now in common use is the oxide of potassium, K_2O . Unfortunately this is a hypothetical compound and is never encountered as such. So every potash salt, even though it be 100 per cent pure, must be recalculated to its equivalent of the hypothetical oxide, K_2O . This, then, is "potash" in the strictest sense of the word, though where it is essential that an exact meaning be conveyed, it is frequently expressed as "actual potash." This practice is followed in this publication, with the practical elimination of the expression " K_2O ."

Another term in common use in the fertilizer trade, but confusing to the layman, is the word "unit." Its meaning may be defined as "one per cent per ton," or in terms of weight, "20 pounds." To illustrate, a potash salt analyzing 50 per cent actual potash (K_2O) is spoken of as containing 50 units of potash and may be quoted at so much per unit. Thus, if quoted at 75 cents per unit, its price per ton would be \$37.50. This term is in general use in designating the concentration of elements of plant food value in commercial fertilizers and is made the basis of guarantee and price.

FORMER SOURCES OF POTASH

TABLE I

POTASH MATERIALS IMPORTED INTO THE UNITED STATES, 1913-1922,
INCLUSIVE

Kainite

| Year | Quantity Potash Salts, Short Tons | Content of Potash (K_2O), Short Tons | Value |
|------|---|--|-------------|
| 1913 | 521,176 | 64,626 | \$2,201,730 |
| 1914 | 351,566 | 43,594 | 1,551,115 |
| 1915 | 7,475 | 927 | 95.44 |
| 1916 | 40 | 5 | 1,173 |
| 1917 | | | |
| 1918 | | | |
| 1919 | 57,427 | 7,121 | 921.481 |
| 1920 | 416,661 | 51,666 | 8,212,621 |
| 1921 | 77,365 | 9,503 | 1,453,854 |
| 1922 | 169,287 | 20,992 | 1,087,895 |

Manure Salts

| Year | Quantity Potash Salts, Short Tons | Content of Potash (K_2O), Short Tons | Value |
|------|---|--|-------------|
| 1913 | 250,529 | 50,106 | \$2,245,509 |
| 1914 | 189,245 | 37,849 | 1,846,475 |
| 1915 | 15,403 | 3,081 | 200,584 |
| 1916 | 1,241 | 248 | 21,273 |
| 1917 | 252 | 50 | 9,047 |
| 1918 | | | |
| 1919 | 45,372 | 9,074 | 1,269,750 |
| 1920 | 348,837 | 69,767 | 10,625,717 |
| 1921 | 43,286 | 8,657 | 792,601 |
| 1922 | 218,406 | 43,681 | 1,948,608 |

TABLE I—*Continued**Muriate (Potassium Chloride)*

| Year | Quantity Potash Salts, Short Tons | Content of Potash (K ₂ O), Short Tons | Value |
|------|---|--|-------------|
| 1913 | 237,630 | 118,815 | \$7,075,745 |
| 1914 | 185,761 | 92,881 | 5,745,385 |
| 1915 | 64,670 | 32,335 | 2,296,606 |
| 1916 | 1,209 | 650 | 348,961 |
| 1917 | 683 | 342 | 158,410 |
| 1918 | 424 | 212 | 102,109 |
| 1919 | 23,202 | 11,601 | 1,783,916 |
| 1920 | 136,194 | 68,097 | 12,703,858 |
| 1921 | 79,642 | 39,821 | 4,777,726 |
| 1922 | 179,484 | 89,742 | 5,485,287 |

Sulphate

| Year | Quantity Potash Salts, Short Tons | Content of Potash (K ₂ O), Short Tons | Value |
|------|---|--|-------------|
| 1913 | 44,349 | 21,554 | \$1,677,429 |
| 1914 | 40,224 | 19,554 | 1,557,224 |
| 1915 | 12,708 | 6,176 | 664,484 |
| 1916 | 1,693 | 823 | 81,684 |
| 1917 | 230 | 112 | 21,702 |
| 1918 | 101 | 49 | 15,329 |
| 1919 | 1,415 | 688 | 188,592 |
| 1920 | 17,006 | 8,265 | 2,343,431 |
| 1921 | 12,459 | 6,055 | 719,183 |
| 1922 | 65,534 | 31,849 | 2,429,407 |

TABLE II

TOTAL POTASH IMPORTED INTO THE UNITED STATES FOR THE TWELVE-YEAR PERIOD, 1913-1924, INCLUSIVE

| Year | Potash (K_2O), Short Tons | Value |
|------|----------------------------------|--------------|
| 1913 | 255,101 | \$13,200,413 |
| 1914 | 193,878 | 10,700,308 |
| 1915 | 42,519 | 3,257,114 |
| 1916 | 1,726 | 453,091 |
| 1917 | 504 | 189,159 |
| 1918 | 261 | 117,438 |
| 1919 | 28,484 | 4,163,739 |
| 1920 | 197,795 | 33,885,627 |
| 1921 | 64,036 | 7,743,364 |
| 1922 | 186,164 | 10,951,197 |
| 1923 | 209,950 | 15,404,572 |
| 1924 | 200,365 | 13,368,127 |

TABLE III

TOTAL POTASH SALTS IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1913, 1923, AND 1924 *

Quoted from "Potash in 1924," by G. R. Mansfield and Leona Boardman, U. S. Geological Survey

| Material | Ap-prox-imate Content (Per Cent) | 1913 | | | | 1923 | | | | 1924 | | | |
|--------------------------------------|----------------------------------|---------------------------------------|-----------------------|-------|-------------|---------------------------------------|-----------------------|-------|------------|---------------------------------------|-----------------------|-------|------------|
| | | Available Content of K ₂ O | | Value | Short tons | Available Content of K ₂ O | | Value | Short tons | Available Content of K ₂ O | | Value | |
| | | Short tons | Per-cent-age of total | | | Short tons | Per-cent-age of total | | | Short tons | Per-cent-age of total | | |
| Used chiefly in fertilizers. | | | | | | | | | | | | | |
| Kaoline..... | 12.4 | 521,176 | 64,626 | 23.9 | \$2,201,730 | 187,833 | 23,291 | 11.1 | \$977,807 | 175,513 | 21,764 | 10.9 | \$892,740 |
| Manure salts..... | 20.0 | 250,529 | 50,106 | 18.5 | 2,245,509 | 301,721 | 60,344 | 28.8 | 2,939,793 | 258,998 | 51,800 | 25.8 | 2,278,484 |
| Muriate..... | 59.0 | 237,630 | 118,815 | 43.8 | 7,075,715 | 151,757 | 75,879 | 36.1 | 4,116,180 | 144,623 | 72,312 | 36.1 | 3,982,288 |
| Sulphate..... | 48.6 | 44,349 | 21,554 | 8.0 | 1,677,429 | 71,300 | 31,696 | 16.5 | 2,599,695 | 84,780 | 41,203 | 20.6 | 2,858,063 |
| | | 1,053,684 | 255,101 | 94.2 | 13,200,413 | 712,701 | 194,210 | 92.5 | 10,633,475 | 663,914 | 187,079 | 93.4 | 10,042,575 |
| Used chiefly in chemical industries: | | | | | | | | | | | | | |
| Bicarbonate..... | 46.0 | 223 | 103 | 1.1 | 20,968 | 161 | 74 | 9 | 19,954 | 185 | 85 | 1 | 25,754 |
| Bitartrate (argol)..... | 20.0 | 14,459 | 2,900 | 1.1 | 2,779,180 | 9,832 | 1,966 | 9 | 1,499,389 | 8,416 | 1,683 | 8 | 1,103,296 |
| Bitartrate (cream of tartar)..... | 25.0 | 75 | 19 | | 28,314 | 640 | 160 | 1 | 194,081 | 766 | 192 | 1 | 165,421 |
| Bromide..... | 39.6 | 4,858 | 2,963 | 1.1 | 272,973 | 4,906 | 10 | | 5,736 | 468 | 185 | 1 | 124,414 |
| Carbonate, crude..... | 61.0 | 344 | 2,963 | 1.1 | 272,973 | 4,906 | 2,993 | 1.4 | 518,632 | 3,569 | 2,177 | 1.1 | 290,396 |
| Carbonate, crude or black salts..... | 50.0 | 6,115 | 4,117 | 1.5 | 393,284 | 5,419 | 4,335 | 2.1 | 685,309 | 6,315 | 5,052 | 2.5 | 698,635 |
| Carbonate, refined..... | 67.0 | 4,117 | 3,456 | 1.3 | 342,056 | 6,749 | 2,565 | 1.2 | 569,399 | 3,760 | 1,429 | 7 | 310,643 |
| Cuscut..... | 80.0 | 4,321 | 3,456 | 1.3 | 342,056 | 6,749 | 2,565 | 1.2 | 569,399 | 3,760 | 1,429 | 7 | 310,643 |
| Chlorate and perchlorate..... | 38.0 | 596 | 226 | 1.1 | 64,468 | 3 | 682 | 3 | 161,825 | 1,411 | 982 | 5 | 232,971 |
| Chromate and dichromate..... | 70.0 | 9 | 4 | 0.002 | 1,819 | 983 | 682 | 3 | 161,825 | 1,411 | 982 | 5 | 232,971 |
| Cyanide..... | 42.0 | 735 | 514 | 2.2 | 216,814 | 36 | 24 | 0.01 | 66,909 | 41 | 17 | 0.01 | 23,308 |
| Ferrocyamide (red prussiate)..... | 44.0 | 331 | 114 | 0.4 | 12,055 | 188 | 83 | 0.3 | 82,293 | 132 | 58 | 0.2 | 40,032 |
| Ferrocyamide (yellow prussiate)..... | 28.0 | 1,706 | 751 | 3 | 388,379 | + | + | + | 82,293 | 132 | 58 | 0.2 | 40,032 |
| Iodide..... | 40.0 | 826 | 163 | 1 | 261,078 | 3,077 | 1,231 | 6 | 137,228 | 772 | 309 | 2 | 54,628 |
| Nitrate (salt-peter), crude..... | 46.0 | 203 | 93 | 0.7 | 22,602 | 2,962 | 1,363 | 1 | 634,921 | 2,279 | 1,048 | 5 | 290,805 |
| Nitrate (salt-peter), refined..... | 29.0 | 273 | 79 | 0.3 | 38,188 | 561 | 163 | 0.1 | 142,887 | 87 | 25 | 0.01 | 13,940 |
| Permanganate..... | 22.0 | 54 | 12 | 0.005 | 13,412 | 164 | 36 | 0.06 | 40,917 | 104 | 23 | 0.01 | 24,003 |
| Rochelle salt..... | 50.0 | | | | | 97 | 48 | | 10,471 | 26 | 13 | | 4,172 |
| All other..... | | | | | | | | | | | | | |
| Grand total..... | | 38,904 | 15,619 | 5.8 | 4,873,452 | 35,824 | 15,740 | 7.5 | 4,771,007 | 28,336 | 13,286 | 6.6 | 3,325,552 |
| | | 1,092,588 | 270,720 | 100.0 | 18,073,805 | 748,525 | 209,950 | 100.0 | 15,404,572 | 692,250 | 200,365 | 100.0 | 13,368,127 |

* The figures in this table were compiled by J. A. Dorsey from the records of the Bureau of Foreign and Domestic Commerce by recalculation from pounds to short tons and to actual potash (K₂O) and by giving the totals for calendar years instead of fiscal years. The tons are calculated to the nearest even unit, and the values are those given in the original records, so that the value given for a high-priced commodity received in small quantity may not be strictly applicable to the quantity given in tons. Furthermore, the values are those placed on the commodities by the shippers and represent the values at point of shipment and do not agree with the market quotations in this country.

† Quantity of iodide imported was as follows: 1923, 24 pounds; 1924, 47 pounds.

TABLE IV
 POTASH IMPORTED INTO THE UNITED STATES IN 1924, IN SHORT TONS*
 [General Imports. The figures in parentheses in the column headings indicate percentage of K₂O]
 Quoted from "Potash in 1924," by G. R. Mansfield and Lena Boardman, U. S. Geological Survey

| Country | Muriate (50) | Sulphate (48.6) | Manure salts (20) | Kalmite (12.4) | Bitar- trate argils or cerams wholes (20) | Bitar- trate argils or cerams of wholes (25) | Caustic (80) | Carbon- ate (61) | Cyanide (70) | Nitrate of, or saltpetre, oxide (40) | Chlorate and per- chlorate (36) | Total | |
|--------------------------------------|-----------------|--------------------|----------------------|-------------------|--|--|-----------------|---------------------|-----------------|--|---|---------------|-----------|
| | | | | | | | | | | | | Short tons | Value |
| Africa: | | | | | | | | | | | | | |
| Algeria and Tunis | | | | | 238 | | | | | | | 238 | \$31,221 |
| Other French Africa | | | | | | 37 | | | | | | 37 | 3,910 |
| Argentina | 330 | 39 | | | 1,369 | 86 | | | | | | 1,764 | 145,317 |
| Austria | | | | | | | | | | | | 2 | 1,400 |
| Belgium | 7,955 | 3,984 | 13,053 | 5,356 | | † | † | | 4 | 35 | | 242 | 619,514 |
| Bulgaria | 1,624 | 36 | 730 | | 12 | | | | 1,326 | 482 | | 30,620 | 251,485 |
| Chile | | | | | 60 | | 399 | 3 | | | | 3,753 | 28,503 |
| Czechoslovakia | | | | | | | | | | | | 1 | 403 |
| Denmark | | | | | | | | | | | | 9 | 4,342 |
| | | | | | | | | | | | | | 2,616 |
| England | 53,485 | 6,337 | 94,480 | 91,086 | 3,835 | 302 | | 2 | | | | 82 | 33,011 |
| France | 80,425 | 71,340 | 144,464 | 77,106 | 53 | 26 | 5,825 | 3,106 | 129 | 21 | 136 | 249,822 | 3,617,959 |
| Germany | | | | | 2 | | | | | 181 | 2,869 | 2,354 | 390,881 |
| Greece | † | † | † | | | | | † | | | | † | 7,760,564 |
| Hongkong | | | | | | | | | | | | | 263 |
| India, British | | | | | 37 | | | | | 84 | | | 393 |
| Ireland | | | | | | | | | | | | 121 | 20,817 |
| Italy | | | | | 1,462 | 25 | | | | | | 1 | 329 |
| Japan | | | | | † | 158 | 37 | 28 | | 1 | 22 | 1,480 | 230,452 |
| Netherlands | 440 | | | | | | | | | | | † | 56 |
| | | | | | | | | | | | | 1,111 | 127,543 |
| Portugal | | | | | 533 | | | | | | | | |
| Scotland | | | | | | | | | | | | 533 | 63,429 |
| Spain | | | | | 111 | | | | | | | | |
| Sweden | | | | | 420 | 38 | 68 | | | | | 114 | 2,476 |
| Switzerland | | | | | | | | | | | | 1,278 | 115,431 |
| | | | | | | | | | | | | 68 | 25,351 |
| | | | | | | | | | | | | 9 | 79,654 |
| Content of potash (K ₂ O) | 144,259 | 84,736 | 253,281 | 173,548 | 8,372 | 763 | 6,329 | 3,139 | 1,459 | 772 | 3,744 | 3,170 | 683,572 |
| | 72,130 | 41,182 | 59,656 | 21,520 | 1,674 | 191 | 5,063 | 1,915 | 1,621 | 309 | 1,348 | 1,585 | 198,594 |

* The figures in this table were compiled by J. A. Dorsey from the records of the Bureau of Foreign and Domestic Commerce by recalculation to short tons and to the actual potash (K₂O) and by giving the totals by the calendar year instead of the fiscal year. The tons are calculated to the nearest even unit. The data represent general imports and include both imports for immediate consumption and those going to warehouses, which may or may not be entered for consumption during the year. They differ slightly from the figures in the preceding table of imports, which represents imports for consumption.

† Less than 1 ton.

THE FOREIGN POTASH INDUSTRIES

THE GERMAN POTASH INDUSTRY

THE German potash industry as it existed before the War has been described from time to time in the technical and lay press. The industry as it exists since its rehabilitation in the period following the War has been described by Assistant Trade Commissioner William T. Daugherty, under date of December 21, 1922. This report is of such excellence that it is made the basis of the following discussion.

OCCURRENCE AND PROPERTIES OF MINES

The War left to Germany one self-contained industry—the potash industry. The pre-war monopoly enjoyed by Germany, broken by the loss of the potash mines in Alsace-Lorraine under the Peace Treaty, is nevertheless not as seriously threatened apparently now as first signs after the War would have seemed to indicate. The superiority of German deposits left: i.e., the purer and more abundant deposits of salts and the simultaneous occurrence of carnallite ($\text{KCl} \cdot \text{MgCl} \cdot 6\text{H}_2\text{O}$), sylvinite ($x\text{KCl}y\text{NaCl}$), and kieserite ($\text{MgSO} \cdot \text{H}_2\text{O}$), as well as lower costs of production, favor Germany on the world market. Germany's expectation of setting a record of sales in the calendar year, 1922, of about 1,330,000 tons of actual potash, or 220,000 tons more than in 1913, out of which total 24.8 per cent have been foreign sales in the first ten months of 1922 (against 45–50 per cent in 1913), seems to confirm this claim. Energetic plans are in progress to penetrate America, and recover Germany's most important pre-war market.

It has been estimated that potential, unmined supplies of German potash amount to about 11,000,000,000 cubic meters, or sufficient to last more than 1000 years, at the present rate of production and demand. (The same estimate puts at 190,000,000 cubic meters the potential stocks of Alsace-Lorraine.)

Production centers of the German potash industry are roughly five, namely: (1) the Hannover district, (2) the South Harz district, (3) the Werra (Thuringia) district, (4) the Stassfurt district, and (5) the Halle, Mansfeld, and Unstrut district, in the order of their approximate production in terms of actual potash, in the first six months of 1922. In October, 1922, 128 shafts were being actively worked in all Germany, while 83 shafts were idle, according to the Kalipruefungsstelle, of Berlin, an official organization, calculating the participation of all German works in total sales.

Rich and abundant supplies of German potash, lying nearer the surface, or more profitably worked for richer content if lying deeper, permit a variety of choice of location for new works. The shifting of production centers, for instance, to the South Harz district, has taken place recently. The famous Stassfurt district, which occupied second place in production in 1921, was reduced to fourth place during the first six months of 1922.

This shifting of production centers is not necessarily measured by the number of active shafts in operation, as some shafts in respective districts are worked more intensively than others. In October, 1922, the Hannover district operated the largest number of shafts, namely, 54 shafts out of 79; the South Harz district, 24 out of 33; Stassfurt, 24 out of 43; the Werra, 14 out of 27; Halle, etc., 12 out of 29.

The maximum depth at which potash is profitably mined in Germany is now about 1200 meters. (The deepest active shaft in Germany is now the "Volkenroda" in the South Harz). As a matter of fact, about 86 per cent of

German potash lies within a 1200-meter depth, while another 10 per cent lies at from 1200 to 1500 meters. Operations at greater depths are embarrassed by high temperatures in the warm, heavily laden mine air, as miners cannot work easily in temperatures exceeding 28° Celsius.

The most favored mines, from the standpoint of seam structure, concentration, and potash content, are probably in the Werra district, which was first penetrated in the nineties. Rich, uniform, and horizontally constructed seams of carnallite as well as carnallitic and sylvinitic "hard salt" (a mixture of chloride of potassium, sulphate of magnesium and sodium chloride, with less water of crystallization than in kainite) lie at a depth of from 300 to 800 meters, bedded in rock salt. The deposits run an average of about 20–24 per cent potassium chloride, and occur simultaneously with kieserite and sylvinite, equally easy to work. With this favored natural occurrence, the concentrating plants, located over or in the vicinity of sunken shafts, are able to produce relatively cheap potassium and magnesium sulphates, as well as the well-known chemical by-products, among which are "bitter" and Glauber's salts, to be discussed below. It is pertinent to note that experiments are in progress by chemists in this district to produce sulphuric acid, at competitive cost, at the works. These experiments, however, are still in the laboratory stage.

A typical occurrence in the Werra district lies beneath the famous Wintershall concentration plant. At 310 meters depth one encounters a 110-meter-thick rock salt seam, with an underlying 2- to 3-meter-thick seam of "hard salt," containing 10–35 per cent hard salt, 15–35 per cent kieserite, and the remaining percentage of rock salt. Operations are in progress in a gallery 2000 meters long beneath Wintershall, for mining the raw salts. A deeper region lies about 75 meters below this one, where tests have shown the occurrence of another 2- to 3-meter seam of 17–30 per cent kieserite and 10–20 per cent hard salt. The deeper deposit is not now being worked in the shaft beneath Win-

tershall, although a similar one is being worked in other shafts in the Werra district.

The famous Stassfurt deposits are nearly 1000 meters thick. The beds are not separately defined layers, but are considered as occurring in four principal regions, containing approximately sixteen different kinds of salts. The first region penetrated as one descends from the surface is the carnallite stratum, about 50 meters thick. It yields 55-60 per cent carnallite, 20-25 per cent rock salt, and about 18 per cent kieserite. The next stratum encountered is kieserite, about 60 meters thick, yielding about 17 per cent kieserite, 13 per cent carnallite, and 65 per cent rock salt. Below this is the polyhalite (K_2SO_4 , $MgSO_4$, $2CaSO_4$, $2H_2O$) region, 60 meters thick, containing roughly $6\frac{1}{2}$ per cent of polyhalite and 91 per cent rock salt. The lowest region is the rock salt and anhydrite ($CaSO_4$) region, yielding 95 per cent of rock salt and 5 per cent anhydrite. The rock salt bed is nearly 700 meters thick in places.

The South Harz deposits resemble the Stassfurt deposits, but the seams are gently undulating, with changing thicknesses. Only the ancient deposit exists. It consists partly of carnallitic salts which occur in considerable thicknesses, and partly of anhydritic sylvinite with lesser thicknesses.

In North Hannover the more ancient and the later deposits occur together, and are formed of carnallite, sylvinite and rock salt occurring together. The strata are of steep construction and irregular in occurrence, being broken. Carnallitic strata here occur in greater thickness than do the sylvinitic seams.

The Halle, Mansfeld and Unstrut deposits generally resemble those of Stassfurt.

PRODUCTION

German production of crude salts, by districts, in three post-war years is shown in the following table:

TABLE V
PRODUCTION OF CRUDE SALTS
(In Metric Tons)

| | 1913 | 1920 | 1921 | *1922 |
|-----------------------|-----------------------------------|------------|-----------|------------|
| Hannover | Regional figures not available | 3,508,544 | 2,912,997 | 3,812,220 |
| Stassfurt | | 2,242,192 | 1,989,829 | 2,038,560 |
| South Harz | | 2,005,122 | 1,746,431 | 2,283,520 |
| Werra | | 2,037,862 | 1,457,128 | 2,373,960 |
| Halle, Mansfeld, etc. | | 1,562,385 | 1,134,794 | 1,279,160 |
| Total | 11,604,511 | 11,356,105 | 9,241,179 | 11,787,420 |

* Loosely estimated on a basis of twice the production in the first six months of 1922. Total production figures of actual potash can probably be discounted by around 25,000 tons.

Production, by districts, in terms of actual potash, is shown in Table VI.

TABLE VI
PRODUCTION IN TERMS OF K_2O
(In Metric Tons)

| | 1920 | 1921 | 1922 |
|-------------------------------|-----------|-----------|-----------|
| Hannover..... | 407,822 | 334,426 | 446,620 |
| Stassfurt..... | 225,454 | 215,494 | 215,620 |
| South Harz..... | 269,060 | 231,720 | 299,080 |
| Werra..... | 233,128 | 170,819 | 273,160 |
| Halle, Mansfeld, Unstrut..... | 161,465 | 114,390 | 131,080 |
| Total..... | 1,296,929 | 1,066,849 | 1,365,560 |

REFINING

At the close of 1922, approximately 76 chemical works out of 80 were in operation in Germany for the purpose of refining the crude salts and separating their constituents into products best suited for fertilizers and for the various technical and industrial enterprises using potash compounds. These compounds are used by photographers, painters, dyers, cleaners, bleachers, weavers, soapmakers, electricians, and manufacturers of fireworks, gun-powder, matches, paper, glass and aniline dyes; they are also used in the preserving industry.

The important feature of refining is the reduction in weight of the crude salts, effected by rejecting useless constituents in order to secure the potash in small bulk. At the present time small bulk is especially desirable on account of high freight rates, which preclude, to a greater extent than they did before the War, the purchase of the raw salts by inland consumers. As a matter of fact, crude carnallite was never used for fertilizers, except in the vicinity of the mines, where transportation charges are not a factor.

Two methods are generally employed in the concentration of the potassium chloride of crude carnallite. One of these is known as the "hot process"; the other, as the "cold process."

By the former process, the coarsely ground carnallite, containing in the crude state an average of about 15 per cent of potassium chloride, is consigned to a large dissolving vat containing a boiling, saturated solution of magnesium and sodium chlorides, where the mixture is agitated and the resulting solution evaporated to a concentration of about 32° Baumé. The easily soluble potassium chloride dissolves, while rock salt, kieserite, and impurities remain as residue. The hot solution of potassium chloride is then drawn off into settling tanks, and thence into crystallizing vats, where it is left for three or four days to crystallize. The residue is washed with cold water, which dissolves the

rock salt but leaves the kieserite in the form of a heavy, white paste. The potash resulting from crystallization contains about 64 per cent potassium chloride. The mother liquor from the crystallizing vats is run off and concentrated (generally in a vacuum apparatus) and on cooling yields practically all of the potash as crystals of pure, artificial carnallite, which is treated as was the crude carnallite, yielding an almost pure potassium chloride in one crystallization. The mother liquor from the artificial carnallite is the so-called waste liquor (Endlaug), which is used in part for the preparation of bromides, magnesium chloride, and other by-products. (See below.) The potassium chloride is washed repeatedly to remove adhering solution of sodium and magnesium chlorides. After drying, the crystals of potassium chloride contain anywhere from 70 to 99 per cent potassium chloride.

The "cold process" came into use after the War during the period of scarcity of coal. It is based on the principle of mixing the carnallite in cold water, so that only the magnesium chloride goes into solution while the potassium chloride is thrown down as a white paste in the mother liquor. This method, however, can only be applied to purer forms of carnallite, as pasty impurities must be avoided in the later stages of the concentration of the potassium chloride.

The concentration of the potassium chloride of "hard salt" and sylvinite involves another process. The raw salt is treated in a hot solution of sodium and potassium chloride which dissolves the potassium chloride, while the rock salt remains as residue. The solution is clarified and cooled, whereupon the potassium chloride is thrown down. The mother liquor, which still contains a good deal of potassium chloride, is used repeatedly for dissolving new quantities of raw salts. There are no waste products in this process.

Potassium chloride is sold for fertilizer on the basis of 80 per cent purity, which is equivalent to 50.4 per cent actual potash. Potassium chloride serves further for the

manufacture of many other potash salts, such as nitrates, chlorates, etc.

Potassium sulphate is manufactured in smaller quantities than potassium chloride, because there is less demand for it on the market. A typical process of manufacture is to mix potassium chloride and kieserite in concentrated solution which precipitates "sulphate of potash-magnesia." A solution of sulphate of potash-magnesia and a given quantity of potassium chloride are boiled together. The less soluble potassium sulphate is precipitated. Commercial sulphate varies from 90 to 98 per cent in purity, equal to 48 to 52.7 per cent of actual potash. A simultaneous occurrence of carnallite and kieserite in the mines, of course, favors the use of this process.

From the above-mentioned residual waste liquor from artificial carnallite in potassium chloride preparation, a number of by-products are derived. Bromine results when these liquors are treated with chlorine gas in a so-called "bromine tower," the product being either liquid bromine, or, if brought into contact with iron shavings, iron bromide. Bromine serves also for the preparation of potassium bromide, sodium bromide and ammonium bromide. These salts are used by pharmacists and photographers, while free bromine is used principally in the manufacture of dyes.

By concentrating the residual mother liquor, the magnesium chloride contained therein is recovered. Magnesium chloride is put on the market in the four forms: crystallized, pulverized, melted, and flakes. The last-named product is exported largely to the United States.

In one plant, the residual waste liquor is the basis of manufacture of hydrochloric acid and chlorine, although this is by no means an important enterprise.

Boracite, occurring in the soluble residues, forms the basis for the production of borax and boracic acid. This also is an unimportant enterprise for commerce, and is of scientific rather than of practical interest.

In one plant the rubidium, occurring in very small

quantity in the crude salts, was once recovered. Rubidium is a metal similar to potassium; it has a certain use in pharmacy, and can be isolated in connection with the preparation of artificial carnallite, above mentioned.

Kieserite, in hot solution which is later cooled, is the basis of the preparation of bitter salts, used in the textile industry in connection with the manufacture of artificial silk, and cotton and silk weaving and dyeing. It is also used in small quantity by the paper industry, and when chemically pure, in pharmacy, as Epsom salts.

Residues containing high percentages of kieserite are the basis of the preparation of Glauber's salt, or sodium sulphate. The raw material, composed of rock salt and kieserite, is dissolved at a slightly elevated temperature to form a highly concentrated solution, which is then cooled. The sodium chloride and magnesium sulphate interact to yield sodium sulphate, which appears as Glauber's salt, while magnesium chloride remains in solution. Calcined Glauber's salt is used largely for glass manufacture, while the crystallized form is used by the textile industry.

A most important by-product of the potash industry is rock salt, which has been sold in greater quantity since the War than ever before; e.g., in 1913, 400,000 tons; 1919, 600,000 tons, and 1920, 1,250,000 tons. The best rock salt-producing region is the Hannover district. The rock salt here contains about 99 per cent sodium chloride.

TOTAL SALES

The following table shows the totals of sales of German potash salts, in terms of actual potash content, to inland and foreign purchasers for the ten-year-period, 1913-22.

It is observed from the table that, except for the year 1921, foreign sales have increased progressively in post-war years. Germany's best customer for potash salts in 1913 was the United States, which purchased 236,884 tons actual potash; Holland came next, purchasing 43,478 tons,

while France bought 33,115 tons. Though foreign sales have decreased in volume in post-war years, the relative importance of these markets is probably not appreciably changed, as is shown by figures for recent years, for instance, those for 1920. In that year, the United States bought 83,602 tons of actual potash from Germany; Holland, 54,347 tons; England, 11,414; and France, 1,975, according to figures given by the German Potash Syndicate.

TABLE VII
TOTAL SALES
(In Metric Tons, K_2O)

| Year | Inland | Foreign | Total |
|-------|---------|---------|-----------|
| 1913 | 604,283 | 506,087 | 1,110,370 |
| 1914 | 537,809 | 366,179 | 903,988 |
| 1915 | 567,098 | 112,779 | 679,877 |
| 1916 | 721,044 | 158,932 | 879,976 |
| 1917 | 871,478 | 132,893 | 1,004,371 |
| 1918 | 859,716 | 141,947 | 991,663 |
| 1919 | 637,033 | 174,970 | 812,003 |
| 1920 | 689,391 | 234,252 | 923,643 |
| 1921 | 768,477 | 152,670 | 921,147 |
| 1922* | 997,500 | 332,500 | 1,330,000 |

* Estimated.

CONSUMPTION OF GERMAN POTASH IN AGRICULTURE AND INDUSTRY

The consumption of potash by German agriculture and industry, respectively, is shown in the following table of sales for the years indicated.

It is evident from the table that the tendency is toward an increasing use of potash by German agriculture in post-war years, as compared with 1913. The sales to industry amounted in 1913 to slightly more than 6 per cent of total sales. In 1921 this percentage was a little more than 5 per cent.

TABLE VIII
CONSUMPTION OF POTASH IN GERMANY
(In Metric Tons, K_2O)

| Year | Agriculture | Industry |
|------|-------------|----------|
| 1913 | 536,103 | 68,180 |
| 1914 | 483,627 | 54,182 |
| 1915 | 520,211 | 46,887 |
| 1916 | 680,561 | 44,483 |
| 1917 | 834,382 | 37,096 |
| 1918 | 821,684 | 38,032 |
| 1919 | 608,767 | 28,266 |
| 1920 | 645,296 | 44,095 |
| 1921 | 720,604 | 47,873 |

Corresponding sales of potash to foreign countries during the same period were as follows:

TABLE IX
FOREIGN CONSUMPTION OF GERMAN POTASH
(In Metric Tons, K_2O)

| Year | Agriculture | Industry |
|------|-------------|----------|
| 1913 | 467,811 | 38,276 |
| 1914 | 340,523 | 25,656 |
| 1915 | 105,493 | 7,286 |
| 1916 | 151,424 | 7,508 |
| 1917 | 126,462 | 6,431 |
| 1918 | 136,661 | 5,286 |
| 1919 | 168,119 | 6,851 |
| 1920 | 225,701 | 8,551 |
| 1921 | 146,641 | 6,029 |

It is evident from these figures that sales to industry, amounting in 1913 to roughly 3.4 per cent of total sales, were decreased approximately to .66 per cent in 1921. It is interesting to note the decrease in the use by foreign industry

of German potash salts with the ushering in of the first year of the Great War.

POTASH CONTROL

After various experiments in regulating the production and sales of potash, extending over a period of about half a century, the German Reichstag passed the so-called Federal Potash Law on May 25, 1910. This law provided that the Government, and not the Potash Syndicate, was to be empowered to fix inland prices for potash. It also took from the Syndicate the right to prescribe the amounts of participation of the various concerns (groups) in total sales, and created a so-called Distribution Center (*Verteilungsstelle*) for this purpose. At the same time, however, an Appeal Commission was created with power to hear appeals against decisions of the Distribution Center.

The real organization of the Potash Syndicate was not directly affected by this law. This organization was regulated through the members, as well as through the sales agreement. Until the outbreak of the Revolution (November, 1918), the organization was not changed.

Socialist parties with majority votes in the Reichstag, after the Revolution, contemplated the socialization of Germany's potash resources. As this proposal was confronted with too many difficulties, an alternative was chosen, namely, the creation of a Federal Potash Council (*Reichskalirat*) with power to control the German potash industry.

The Federal Potash Council is composed of thirty members, and includes representatives of potash producers, dealers, and wholesale consumers (agriculture and the chemical industry). In addition, three members of the Potash Syndicate are admitted, as well as one expert in potash mining. Employers and labor are represented in equal number in the Council.

The Council supervises the industry, fixes prices, and

issues regulations applying to the industry. It has the right to forbid the sinking of shafts, and to close up potash works.

Besides the Council there are other bodies, such as the Kalipruefungsstelle, above mentioned, and the Appeal Office. Both of these latter perform the same duty as was written into the law of 1910 for the Distribution Center and the Appeal Commission. There also exists a Potash Wages Examining Office (Kalilohnpruefungsstelle), as well as a Technical Agricultural Office, whose functions are explained by their names.

Potash producers are organized into a sales organization, the Potash Syndicate, which alone has the right to sell potash at home and abroad.

In order to concentrate production in the most modern and productive plants, the Government passed the so-called "Closing Down Regulation" (Stillegungsverordnung) on October 22, 1921. This regulation provides for the closing down of works. A number of establishments in which the production costs were too high were voluntarily shut down by the concerns controlling them.

LABOR AND WAGES

At the close of 1922 approximately 25,000 miners and their helpers were employed underground by the potash industry, while 30,000 were occupied in the chemical works and in the administration branch of the industry above ground. At the beginning of 1925, this personnel had been reduced from 55,000 to 29,000 employees, indicating the radical nature of the reorganization and retrenchment which has taken place within the industry since the War.

Two underground crews are employed, each of which works a shift of $7\frac{1}{2}$ hours a day, inclusive of time taken in entering and leaving the mines. The average wage per miner per shift in November of that year was 2000 marks. It is pertinent also to note that the centers of potash mining,

except the Halle district, are in agricultural districts, and isolated from centers of population. It is usual for the potash miner to own his small plot of land, which he is able to farm when not at work in the mines. The potash industry is therefore marked by less labor discontent than perhaps any other industry in Germany, a most important factor at this time.

Early in 1925, the wages of potash miners were, on the basis of the readjusted currency, 4.50 marks per shift. They were subsequently raised to 4.80 marks per shift.

PRODUCTION COSTS

It is estimated that the production costs of German potash now obtaining vary from 8 marks to 14 marks per kilogram of actual potash, depending on the efficiency of the plant. Entering into this estimate are wages (40 to 55 per cent), power (8 per cent), heating dissolving vats and evaporators (10 to 12 per cent), and supplies (15 per cent).

Transportation charges from Central German points to Hamburg are about 9 marks per ton of potash salts, and from Hamburg to New York, \$2.50 to \$3.00 per ton.

Under the potash laws now in effect, sustaining the Potash Syndicate and the Federal Potash Council, prices are maintained at a high enough figure to permit the smaller and less efficient plants to operate at a profit.

PRODUCTION CAPACITY

Germany's capacity for the manufacture of potassium chloride for fertilizer and for the further preparation of potassium salts for the chemical and pharmaceutical industries is only limited by the physical ability of its many reducing plants to treat the product from nearby mines where carnallite, sylvinit, hard salts, etc., of which potassium chloride is the essential constituent, occur in abundance.

Considering the record year of potassium chloride production, 1918, when German plants produced the high figure

of 292,506 metric tons of actual potash as potassium chloride, despite the fact that all producing plants were operating at about 66 per cent of capacity, present capacity in potassium chloride can be estimated at about 390,000 tons actual potash annually.

Incidentally, the record year of production of 40 per cent fertilizer salts, 1922, showed a total output of 506,618 tons actual potash, or not a great deal less than twice the record figure for potash as potassium chloride. This is easily accounted for by the fact that the salts that are richer in potash are reduced to potassium chloride, while those poorer in potash are worked up into fertilizer salts. Both are reduced by the same method.

TABLE X

CHEMICAL COMPOSITION OF CERTAIN POTASH AND ASSOCIATED MINERALS AND SALTS

| Name of Mineral | Composition |
|---------------------------|--|
| Alumite..... | $K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$ |
| Anhydrite..... | $CaSO_4$ |
| Boracite..... | $6MgO \cdot MgCl_2 \cdot 8B_2O_3$ |
| Borax..... | $Na_2B_4O_7 \cdot 10H_2O$ |
| Carnallite..... | $KCl \cdot MgCl_2 \cdot 6H_2O$ |
| Feldspar..... | $K_2O \cdot Al_2O_3 \cdot 6SiO_2$ |
| Gaylussite..... | $Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O$ |
| Glauconite..... | $KFe'''Si_2O_6 \cdot nH_2O$ |
| Glazerite..... | $3K_2SO_4 \cdot Na_2SO_4$ |
| Gypsum..... | $CaSO_4 \cdot 2H_2O$ |
| Halite..... | $NaCl$ |
| Hanksite..... | $KCl \cdot 9Na_2SO_4 \cdot 2Na_2CO_3$ |
| Kainite..... | $KCl \cdot MgSO_4 \cdot 3H_2O$ |
| Kieserite..... | $MgSO_4 \cdot H_2O$ |
| Natron..... | $Na_2CO_3 \cdot 10H_2O$ |
| Penta-calcium sulphate... | $K_2SO_4 \cdot 5CaSO_4 \cdot H_2O$ |
| Polyhalite..... | $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$ |
| Sylvinite..... | $KCl \cdot xNaCl$ |
| Syngenite..... | $K_2SO_4 \cdot CaSO_4 \cdot H_2O$ |
| Thenardite..... | Na_2SO_4 |

Theoretically, capacity output of fertilizer salts is also one-third more than this record figure. It is conservatively

estimated at 675,000 metric tons actual potash. The combined potential output of 80 per cent potassium chloride and 40 per cent fertilizer salts is over 1,000,000 metric tons actual potash annually.

It will be remembered that Germany's record year of production in all potash salts, 1922, showed an output of about 1,300,000 tons potash. If this production resulted from the operation of all works at but two-thirds capacity, Germany is capable of producing about 1,730,000 tons actual potash annually, with present plant equipment. World consumption in 1922, it will be remembered, was but about 1,600,000 tons.

THE FRENCH POTASH INDUSTRY

The French (Alsatian) potash deposits lie in the Department of Haut-Rhin between the cities of Colmar and Mülhouse, close to the Eastern slopes of the Vosges Mountains. They consist of a deposit of sylvinite, about 200 square kilometers in area, which is estimated to contain about 300,000,000 tons of potassium chloride. This deposit, discovered in 1904 and under active exploitation since 1910, is considered the richest in quality in Europe. Under the Treaty of Versailles this deposit, with the exception of 2400 hectares which are the property of the Société par Actions des Mines de Kali Sainte-Thérèse, came into the possession of the French Government. The output of both groups is marketed at present through the sales agency, the Société Commerciale des Potasses d'Alsace, formed in 1919.

As operated under the German Imperial Potash Syndicate, this deposit was exploited by four groups:

1. The Société par Actions des Mines de Kali Sainte-Thérèse, controlling, as stated, 2400 hectares;
2. The Deutsche Kaliverke, H. G., a stock company controlling 11,500 hectares;
3. The Wintershall group, in which the Imperial Government participated and which controlled 3600 hectares; and

4. The Roechling group, likewise partly owned by the Imperial Government, controlling 3200 hectares.

Thus, out of a total of 20,700 hectares, 18,300 hectares have come into the possession of the French Government.

Under Syndicate control and allocation, the Alsatian Mines were developed to the production indicated in the following tabulation, in the last year there shown, eleven shafts being in operation.

TABLE XI

OUTPUT OF ALSATIAN MINES WHILE UNDER GERMAN CONTROL,
PRE-WAR YEARS

| Year | Tons Crude Salts |
|------|------------------|
| 1910 | 38,431 |
| 1911 | 102,644 |
| 1912 | 137,243 |
| 1913 | 350,341 |

Following the Armistice and the occupation of Alsace by the French Military Forces, under the French laws and decrees repressing commerce with the enemy and creating war sequesters, the potash deposits, with the exception of the Kali Sainte-Thérèse, were taken away from their operators and placed under military sequesters. In January, 1918, a civil sequester was created for the operation of the mines, under which the exploitation of the properties was combined. In January, 1920, the Treaty of Versailles went into effect, its terms legitimatizing the French sequesters.

Under French governmental control these properties have been made to yield much greater quantities of potash than formerly, as shown in the table on p. 26.

In 1913 only eleven shafts were in operation, while in 1922, it is reported, this number had been increased to seventeen. This development, it will be observed, had been accompanied by an increase in production from 350,000

tons crude salts, equivalent to 58,000 tons actual potash, in 1913, to 1,222,000 tons, equivalent to 195,000 tons actual potash, in 1920.

TABLE XII
OUTPUT IN TONS OF CRUDE SALTS OF ALSATIAN MINES UNDER
FRENCH CONTROL

| Year | Government | Kali Sainte Thérèse | Total |
|------|------------|---------------------|-----------|
| 1919 | 500,000 | 89,000 | 589,000 |
| 1920 | 1,066,000 | 156,000 | 1,222,000 |
| 1921 | 759,000 | 145,000 | 904,000 |
| 1922 | 2,945,000 | 382,000 | 3,327,000 |
| 1923 | 1,132,000 | 446,000 | 1,578,000 |
| 1924 | 1,230,000 | | |

Among the Alsatian properties there were twenty shafts, some of which had never been put into operation. In their competition with the 200 shafts of the German producers, the French are accordingly considerably handicapped. They likewise possess fewer refining plants. While the crude salts from the Alsatian deposits contain an average concentration of 16 per cent actual potash the operators there are further handicapped by the scarcity of sulphate and the complete absence of kieserite, and their consequent inability to produce potassium sulphate and particularly sulphate of potash-magnesia. Their product accordingly is principally potassium chloride.

In order to overcome this handicap, attempts have been made to employ sulphuric acid on potassium chloride, and some potassium sulphate has been exported, but the production costs are reported to be too great to permit profitable competition. The occurrence of clay in Alsatian deposits is said to offer another disadvantage, preventing the most efficient concentration of the raw salts. The average Alsatian salts are somewhat superior to the German salts now being mined in that they contain 16 per cent actual

potash as compared with 12 per cent in the latter. This advantage is offset, however, by the fact that the two strata of the Alsatian deposits have a combined thickness of only about 3.5 to 4 meters, while the average thickness of the main Central German deposits varies between 30 and 50 meters, in the latter case admitting of cheaper mass-mining operations.

Owing to the less advantageous situation of the French mines with respect to available seaports, transportation charges to the foreign market are greater for the French than for the German potash. Three ports are available to the French—Antwerp, Dunkirk, and Le Havre. Freight charges per ton of salts in carload lots to Antwerp by way of Strasbourg and the Rhine are 25.65 francs, to Dunkirk 38.05 francs, and to Le Havre 41.60 francs. These are to be contrasted with 9 marks per ton for German salts from Central Germany to Hamburg.

The acquisition by France of the Alsatian potash deposits was hailed by some as the termination of German dominance of the world potash situation. It was assumed that an active competition between the two national groups of producers would ensue and would result in competitive prices below those obtaining before the War. It was believed by others that lack of experience and other handicaps would prevent the French from successfully meeting the opposition of the more powerful and experienced German group.

The question was never put to the test on an efficiency basis, however, but on a political one, as the two came to an agreement, in August, 1924, whereby the American market, the most important foreign market, was to be divided between them in the ratio of $62\frac{1}{2}$ per cent to the German group and $37\frac{1}{2}$ per cent to the French. Early in 1925, this agreement was broadened and strengthened to include certain other nations to which potash was being exported, a slightly higher ratio being awarded the German group. This agreement, highly advantageous to the French, has put at rest all immediate hopes for cheaper potash for American

agriculture, at the same time fixing the price at a figure which, as compared with the pre-war price, must be regarded as satisfactory.

THE POLISH POTASH INDUSTRY

The Polish deposits of potash are located near the salt mines of the Carpathian region of Galician Poland, in the districts of Kalusz, Stebnik, Drohobycz, and Stanislawow. Here the potash is found in four different horizons, in lenticular beds attaining a thickness of 20 feet, interbedded with rock salt and saline clay. The deposits consist principally of kainite and sylvinite, with some carnallite. The kainite is said to contain 10 per cent actual potash, and the sylvinite, 20 to 30 per cent. The Stebnik salts, according to Polish chemists, contain 25 per cent potassium sulphate.

EARLY POTASH DEVELOPMENTS

Potash mining in Poland dates back to 1862; but as the mines were the property of the Austrian Government and subject to governmental apathy, the industry did not develop to any appreciable extent until 1900 when State restrictions became less severe. From 1900 to 1912 inclusive, the total production of the Kalusz fields amounted to 170,000 metric tons, or an average of slightly over 13,000 tons a year. In 1913—a period of transition from governmental to private ownership—the production fell to 2344 tons. There are no figures for the War period, when the industry was practically idle. Work recommenced in 1919, and in 1920 the production reached 6789 metric tons. During the entire fifty years of State ownership the Austrian Government made only five new borings.

Extensive prospecting has since been conducted. Five new deposits have been discovered at Kalusz within a comparatively small area tested, and several new companies have been organized.

TRADE IN POTASH

Nearly all of Poland's pre-war potash production was used in Galicia and Bukowina. About one-fifth, in the form of potash fertilizer, was exported to Moravia, Austria, and Dalmatia. Practically the entire production of chlorides went to the Vienna ammunition factories. Because of the small home production, even Galician Poland formerly imported potash salts.

PRESENT PRODUCTION

The Polish potash industry may be described as essentially a post-war development. The recent growth of the industry is shown by the following tabulation:

TABLE XIII
GROWTH OF THE POLISH POTASH INDUSTRY

| Year | Kainite | Sylvinite | Total Salts |
|------|---------|-----------|-------------|
| 1913 | 2,344 | ..... | 2,344 |
| 1920 | ..... | ..... | 6,789 |
| 1921 | 182 | 15,329 | 15,511 |
| 1922 | 2,520 | 43,563 | 46,083 |
| 1923 | 22,128 | 39,375 | 61,503 |
| 1924 | 23,545 | 57,875 | 81,420 |

Present production is now centered in the Drohobycz and Stanislawow districts, in each of which, at the close of 1924, a deposit was being actively exploited. In the former district, where 127 men were employed, the production was 17,708 tons of kainite; and in the latter district, with a personnel of 371 employees, the production was 5837 tons of kainite and 57,875 tons of sylvinite, or a total for this district of 63,712 tons crude salts.

THE ITALIAN POTASH INDUSTRY

The Italian potash industry is based on the two potash minerals, alunite and leucite.

Near Tolfa are found deposits of alunite which in 1908 were estimated to contain about 200,000 metric tons. In 1914, 3700 metric tons, and in 1915, 4800 metric tons were processed for the manufacture of potash salts.

Of much greater importance are the several leucite deposits, leucitic lavas containing 7.5 to 9 per cent potash, which in the aggregate have been estimated to contain over 8 billion metric tons of actual potash.

It is the latter which have recently been placed under more intensive exploitation and which now assume importance as the basis of a potash industry. It is believed that this industry is potentially capable of being developed to such a degree as to render the Italian nation independent of foreign sources of potash.

The leucite from *Roc camorfinia* has been found to be practically free from magnesium and sodium and to contain over 10 per cent potash as mined. The Societa Italiana Potassa has established a plant at Sessa Aurunca, in Caserta, for the processing of these lavas for the extraction of potash, aluminium compounds and silica.

These lavas, made up of leucite crystals and gangue, can be concentrated magnetically since the gangue contains enough iron to render it magnetic. For this purpose the material is crushed to a fineness of about $\frac{1}{16}$ inch. The resulting concentrate contains 18 per cent potash, 23 per cent alumina, and 55 per cent silica. It is leached with acid, whereupon the potash and alumina go into solution as the appropriate salts, and the silica and gangue remain as an insoluble residue. The preferred procedure prescribes leaching with warm concentrated hydrochloric acid to such a concentration that, on cooling, potassium chloride is crystallized. From the mother liquor, aluminium chloride is precipitated by hydrochloric acid gas and is then subjected

to thermal decomposition to yield alumina and gaseous hydrochloric acid.

For the preparation of potash alum, sulphuric acid is substituted for the hydrochloric. In this case the heat of dilution of the acid produces an effective temperature of 95° C. After the leaching, alum crystallizes on cooling.

THE SPANISH POTASH DEPOSITS

During the pre-war years the deposits of potash in Spain attracted a great deal of attention as being the only known European deposits not under German dominance.

These deposits, discovered in 1912 while explorations were being made of an old salt deposit, lie north to northwest of Barcelona, and extend in an east-to-west direction about 75 miles between the towns of Vich and Balagner, with a maximum width of about 18 miles. The principal activities have been localized near the village of Suria.

During this exploration period companies of various nationalities were formed for the exploitation of the deposits, and considerable preliminary work was done by American interests. While some of these groups retain their concessions, active exploitation of the deposits is being carried on at present by only one concern, the Minas de Potasa de Suria, S. A., organized in 1920 and backed by Spanish and Belgian interests.

Up to the present time, 23 shafts have been put down in this field, in 18 of which potash strata have been encountered. The shafts vary in depth from 305 to 1187 meters. The sections of potash strata explored vary in thickness from 35 to 205 meters and they occur at depths of 200 to 800 meters. In certain areas two beds of carnallite and a lower bed of sylvinite have been encountered. The strata are very intricately folded and it is not always apparent at what angle they are being penetrated. Considerable care is therefore essential in distinguishing between the actual and the apparent thickness of the strata.

On the basis of available analyses, the richness of the

Spanish potash salts appears to be fairly good. The content in actual potash of the carnallite varies from 12.5 per cent to 15 per cent, although certain specimens have shown a potash content of over 20 per cent. Three specimens of sylvinite, described as typical, were shown to contain from 72 to 97 per cent potassium chloride, equivalent to 45 to 61 per cent actual potash. The complete analysis of a specimen of this salt, containing 65.5 per cent potassium chloride, showed the presence also of 31 per cent sodium chloride and about 1 per cent each of calcium and magnesium salts.

On the basis of the exploration so far completed, the Spanish deposits are estimated to contain approximately 2 billion tons of crude salts, equivalent to an available 268,000,000 tons of actual potash.

The Minas de Potasa de Suria, S. A., has put down 12 shafts, including a master shaft, 350 meters deep and 6 meters in cross-section, and has constructed some 3000 meters of gallery. Refining plants are now under construction which will have an estimated capacity of 10,000 tons of crude salts per day. So far only a few thousand tons have been produced.

Such an output would supply the domestic market and leave a large surplus for export. While Spain at present imports a considerable tonnage of potash salts, it is evident that unless the Spanish producers develop a greatly enlarged domestic demand for their product they will have to anticipate severe competition in attempting to dispose of such a considerable tonnage in the world market. That they will be able to enjoy the exclusive exploitation of their domestic market is indicated by the fact that a protective tariff of 100 pesetas per ton of potash salts has already been imposed on the foreign commodity.

From the facts known at present, it is impossible to conclude that the Spanish potash deposits will have any significant influence on the world potash situation other than that represented by the loss of the Spanish potash market to the present German-French group of producers.

At least it may be said that an appreciation of post-war conditions deprives these deposits of much of the interest and importance which they formerly held.

THE JAPANESE POTASH INDUSTRY

Very little detailed information is at hand relative to the Japanese potash industry. Having its origin during the Russo-Japanese War, it was developed to the point where it provided the Japanese people with all the potash they required, leaving a surplus for export. Kelp is the raw material from which the bulk is manufactured.

The Japanese kelp industry has long been an important one, food-stuffs and sizing being the principal products. For this industry, kelp has been extensively cultivated for many years. Cheap labor has made it possible for this industry to be built up on the basis of even the small kelps such as those found on our Atlantic Coast. Large-scale, mechanical harvesting, as practiced on the Pacific Coast of the United States, is not possible in Japan.

For potash manufacture, kelp is harvested by manual labor, largely by women divers, is sun-dried and then shipped to a central factory where it is processed. Various by-products are recovered, an important one being iodine. A sufficient quantity of that commodity is produced to provide an excess for export, as in the case of potash.

This industry, providing two national necessities, is a valuable illustration of the satisfactory and permanent solution of a national problem through the application of chemical ingenuity.

POTASSIUM NITRATE FROM CHILE

The raw material, caliche, from which sodium nitrate is extracted in the Chilean nitrate industry, contains a variable though considerable percentage of soluble potash salts, recoverable as potassium nitrate. At present a portion of this is crystallized together with the sodium nitrate and is

sold as such, and a portion is lost as unextracted material cast on the dumps.

In the past very little attention has been paid to by-products, crude sodium nitrate being practically the only product sought, and that being secured in the simplest manner possible. But in at least one instance, representing an important exception, by-product recovery has been studied and as a consequence a considerable output of potassium nitrate has resulted. This is the beginning of what may become an important development since in the Chilean nitrate industry competition of air-nitrates and the consequent loss of important markets and the threatened loss of others are forcing the consideration of more efficient methods of operation, both to reduce manufacturing costs and to increase the value of the products. This will result in by-product recovery, and among by-products potassium nitrate will play a conspicuous rôle.¹

Such quantities of potassium nitrate as are produced in Chile will be available principally for American use, since Europe manufactures both potash and nitrate in amounts practically sufficient for her requirements.

At present there are no proceeds from potash, the presence of that constituent in sodium nitrate carrying no premium. The potassium nitrate, separated and sold as such, would find ready acceptance in the present market where it already has a recognized value both in the fertilizer and the chemical industries. It would be particularly acceptable for use in the manufacture of the proposed concentrated fertilizers with a basis of ammonium phosphate, where it is needed to "boost" both the potash and the nitrogen content of a mixture. A convenient source of potassium nitrate is required by that program, a need which will be met in some way. Potassium nitrate from Chilean caliche will find there an appreciative market.

The quantities ultimately to be gotten are a matter of

¹ The Efficient Recovery of Nitrates from Caliche. Turrentine. J. Ind. Eng. Chem., **15**, 853 (1923).

speculation. An estimate of 120,000 tons actual potash per annum has been given as representing the quantity now contained as a part of the sodium nitrate there manufactured. This figure is useful as illustrating the potentialities of that source. The total quantity obtainable there is several times greater. But this statement must not be taken as pertaining to the probabilities, as changes within that industry must be revolutionary in character before even the smaller quantity of potassium nitrate is there produced.

PRICES OF POTASH

Table XIV (see p. 36), presenting the price range of European and American potash in the American market for the years 1913 to 1925, reveals the surprising fact that present prices are lower than those in effect during pre-war years.

For example, in 1913, both kainite and manure salts were quoted at 68 cents per unit, while in 1924 kainite was quoted at 52 cents and manure salts at 47 cents per unit.

FACTORS WITHIN THE GERMAN INDUSTRY

Various factors have conspired to make this low price possible. For a period the inflated mark gave Germany the advantage in exchange rates and at the same time resulted in relatively low wages. During this period it was the policy of the German people to invest the mark, the value of which was declining, in goods of more permanent value. Accordingly the German farmer purchased and stored supplies of potash, greatly increasing the domestic business of the potash producers for the time being and enabling them to grant price concessions in the foreign market. This period was followed by the stabilization of the mark, resulting in greatly decreased potash sales in the home market and consequent demoralization within the industry, making it highly desirable that foreign sales be stimulated through price concessions.

TABLE XIV

PRICE OF POTASH (PER UNIT OF K_2O), FOR THE PERIOD, JAN., 1913-JULY, 1925, INCLUSIVE

| Year | Muriate, per Unit | Sulphate, per Unit | Manure Salts, per Unit | Kainite, per Unit |
|----------------|----------------------|-----------------------|---------------------------|----------------------|
| 1913: | | | | |
| January..... | \$0.76 | \$0.96 | \$0.68 | \$0.68 |
| February..... | .76 | .96 | .68 | .68 |
| March..... | .76 | .96 | .68 | .68 |
| April..... | .76 | .96 | .68 | .68 |
| May..... | .76 | .96 | .68 | .68 |
| June..... | .76 | .96 | .68 | .68 |
| July..... | .76 | .96 | .68 | .68 |
| August..... | .76 | .96 | .68 | .68 |
| September..... | .76 | .96 | .68 | .68 |
| October..... | .76 | .96 | .68 | .68 |
| November..... | .76 | .96 | .68 | .68 |
| December..... | .76 | .96 | .68 | .68 |
| 1914: | | | | |
| January..... | .77 | .98 | .68 | .67 |
| February..... | .77 | .98 | .68 | .67 |
| March..... | .77 | .98 | .68 | .67 |
| April..... | .77 | .98 | .68 | .67 |
| May..... | .77 | .98 | .68 | .67 |
| June..... | .77 | .98 | .68 | .67 |
| July..... | .77 | .98 | .68 | .67 |
| August..... | .78 | .98 | .68 | .67 |
| September..... | .78 | .98 | .68 | .67 |
| October..... | .78 | .98 | .68 | .67 |
| November..... | .78 | .98 | .68 | .67 |
| December..... | .78 | .98 | .68 | .67 |
| 1915: | | | | |
| January..... | No quot. | No quot. | No quot. | No quot. |
| February..... | No quot. | No quot. | No quot. | No quot. |
| March..... | 1.18 | 1.25 | 1.35 | No quot. |
| April..... | 3.00 | 2.88 | 1.45 | No quot. |
| May..... | 2.95 | 2.88 | 1.60 | No quot. |
| June..... | 4.40 | 4.06 | 2.50 | No quot. |
| July..... | 4.82 | 4.23 | 2.75 | 3.63 |
| August..... | 4.90 | 4.23 | 3.00 | 3.63 |
| September..... | 4.90 | 4.23 | 3.00 | 3.63 |
| October..... | 4.90 | 4.23 | 3.00 | 3.63 |
| November..... | 8.26 | 7.81 | 3.00 | 3.63 |
| December..... | 9.87 | 9.05 | 3.00 | 3.63 |

TABLE XIV—*Continued*

| Year | Muriate, per Unit | Sulphate, per Unit | Manure Salts, per Unit | Kainite, per Unit |
|----------------|----------------------|-----------------------|---------------------------|----------------------|
| 1916: | | | | |
| January..... | \$9.27 | \$8.12 | \$3.00 | \$3.63 |
| February..... | 9.00 | 6.94 | 2.75 | 3.63 |
| March..... | 8.44 | 6.94 | 2.75 | 3.63 |
| April..... | 8.06 | 6.94 | 2.75 | 3.63 |
| May..... | 7.34 | 6.94 | 2.75 | 3.63 |
| June..... | 6.33 | 5.39 | 2.75 | 3.63 |
| July..... | 5.98 | 5.93 | 2.75 | 3.63 |
| August..... | 6.33 | 5.93 | 2.75 | 3.63 |
| September..... | 7.42 | 5.93 | 2.75 | 3.63 |
| October..... | 8.56 | 5.93 | 2.75 | 3.63 |
| November..... | 8.56 | 5.93 | 2.75 | 3.63 |
| December..... | 8.56 | 5.93 | 2.75 | 3.63 |
| 1917: | | | | |
| January..... | 8.01 | 5.93 | 2.75 | 3.63 |
| February..... | 8.58 | 5.93 | 2.75 | 3.63 |
| March..... | 8.66 | 5.93 | 2.75 | 3.63 |
| April..... | 7.72 | 5.93 | 2.75 | 3.63 |
| May..... | 8.51 | 5.93 | 2.75 | 3.63 |
| June..... | 8.06 | 5.93 | 2.75 | 3.63 |
| July..... | 7.60 | 5.93 | 2.75 | 3.63 |
| August..... | 7.72 | 5.93 | 2.75 | 3.63 |
| September..... | 7.17 | 6.66 | Nom. | Nom. |
| October..... | 6.75 | 6.17 | Nom. | Nom. |
| November..... | 6.83 | 7.58 | Nom. | Nom. |
| December..... | 6.93 | 7.45 | Nom. | Nom. |
| 1918: | | | | |
| January..... | 6.90 | 7.30 | Nom. | Nom. |
| February..... | 6.88 | 7.30 | Nom. | Nom. |
| March..... | 6.88 | 7.30 | Nom. | Nom. |
| April..... | 6.78 | 7.97 | Nom. | Nom. |
| May..... | 6.78 | 7.97 | Nom. | Nom. |
| June..... | 6.13 | 7.97 | Nom. | Nom. |
| July..... | 5.64 | 7.01 | Nom. | Nom. |
| August..... | 5.64 | 7.01 | Nom. | Nom. |
| September..... | 5.64 | 7.01 | Nom. | Nom. |
| October..... | 5.64 | 7.01 | Nom. | Nom. |
| November..... | 5.64 | 7.01 | Nom. | Nom. |
| December..... | 5.64 | 7.01 | Nom. | Nom. |

TABLE XIV—*Continued*

| Year | Muriate, per Unit | Sulphate, per Unit | Manure Salts, per Unit | Kainite, per Unit |
|-----------------|----------------------|-----------------------|---------------------------|----------------------|
| 1919: | | | | |
| January | \$5.54 | \$5.93 | Nom. | Nom. |
| February | 5.54 | 5.93 | Nom. | Nom. |
| March | 5.21 | 5.14 | Nom. | Nom. |
| April | Nom. | Nom. | Nom. | Nom. |
| May | Nom. | Nom. | Nom. | Nom. |
| June | 3.31 | Nom. | Nom. | Nom. |
| July | 2.37 | Nom. | Nom. | Nom. |
| August | 2.37 | Nom. | Nom. | Nom. |
| September | 2.17 | Nom. | Nom. | Nom. |
| October | 2.47 | Nom. | Nom. | Nom. |
| November | 2.47 | Nom. | Nom. | Nom. |
| December | 2.81 | Nom. | Nom. | Nom. |
| 1920: | | | | |
| January | 2.88 | Nom. | No quot. | No quot. |
| February | 2.93 | 4.00 | No quot. | No quot. |
| March | 2.67 | 4.00 | No quot. | No quot. |
| April | 2.53 | 4.00 | No quot. | No quot. |
| May | 2.49 | 3.75 | No quot. | No quot. |
| June | 2.40 | 3.50 | No quot. | No quot. |
| July | 2.40 | 3.50 | No quot. | No quot. |
| August | 2.48 | 3.75 | No quot. | No quot. |
| September | 2.33 | 2.98 | No quot. | No quot. |
| October | 2.19 | 2.85 | No quot. | No quot. |
| November | 2.17 | 2.85 | No quot. | No quot. |
| December | 2.13 | 2.85 | No quot. | No quot. |
| 1921: | | | | |
| January | 1.66 | 2.41 | No quot. | No quot. |
| February | 1.50 | 2.15 | No quot. | No quot. |
| March | 1.39 | 2.08 | 1.11 | 1.11 |
| April | 1.11 | 1.78 | 1.49 | .97 |
| May | 1.02 | 1.50 | .86 | .85 |
| June | .99 | 1.38 | .75 | .78 |
| July | .93 | 1.35 | .78 | .78 |
| August | .88 | 1.28 | .75 | .75 |
| September | .85 | 1.23 | .73 | .73 |
| October | .80 | 1.09 | .62 | .67 |
| November | .74 | .94 | .55 | .60 |
| December | .73 | .94 | .55 | .60 |

TABLE XIV—*Continued*

| Year | Muriate, per Unit | Sulphate, per Unit | Manure Salts, per Unit | Kainite, per Unit |
|-----------------|----------------------|-----------------------|---------------------------|----------------------|
| 1922: | | | | |
| January | \$0.73 | \$0.95 | \$0.55 | \$0.60 |
| February | .71 | .95 | .55 | .60 |
| March | .70 | .90 | .55 | .60 |
| April | .70 | .91 | .55 | .60 |
| May | .65 | .85 | .52 | .57 |
| June | .60 | .80 | .48 | .54 |
| July | .61 | .80 | .49 | .60 |
| August | .70 | .80 | .49 | .60 |
| September | .68 | .80 | .49 | .61 |
| October | .68 | .80 | .49 | .61 |
| November | .71 | .94 | .53 | .58 |
| December | .71 | .94 | .53 | .58 |
| 1923: | | | | |
| January | .71 | .91 | .53 | .58 |
| February | .71 | .91 | .53 | .58 |
| March | .71 | .91 | .53 | .58 |
| April | .71 | .91 | .53 | .58 |
| May | .69 | .87 | .53 | .58 |
| June | .69 | .87 | .53 | .58 |
| July | .69 | .87 | .53 | .58 |
| August | .62 | .79 | .47 | .52 |
| September | .62 | .79 | .47 | .52 |
| October | .62 | .79 | .47 | .52 |
| November | .62 | .79 | .47 | .52 |
| December | .62 | .83 | .47 | .52 |
| 1924: | | | | |
| January | .62 | .83 | .47 | .52 |
| February | .62 | .83 | .47 | .52 |
| March | .62 | .83 | .47 | .52 |
| April | .62 | .83 | .47 | .52 |
| May | .62 | .83 | .47 | .52 |
| June | .62 | .83 | .47 | .52 |
| July | .62 | .83 | .47 | .52 |
| August | .62 | .83 | .47 | .52 |
| September | .67 | .83 | .53 | .63 |
| October | .67 | .89 | .53 | .63 |
| November | .67 | .89 | .53 | .63 |
| December | .67 | .89 | .53 | .63 |

TABLE XIV—*Continued*

| Year | Muriate, per Unit | Sulphate, per Unit | Manure Salts, per Unit | Kainite, per Unit |
|---------------|----------------------|-----------------------|---------------------------|----------------------|
| 1925: | | | | |
| January..... | \$0.67 | \$0.89 | \$0.53 | \$0.63 |
| February..... | .67 | .89 | .53 | .63 |
| March..... | .67 | .89 | .53 | .63 |
| April..... | .67 | .89 | .55 | .63 |
| May..... | .67 | .89 | .55 | .63 |
| June..... | .67 | .89 | .55 | .63 |
| July..... | .67 | .89 | .55 | .63 |

During this period there was a marked reorganization of the potash industry, resulting in the closing down of many mines less advantageously situated with respect to production costs, the number in operation being reduced to 60 shafts out of a total of 218 potential producers. This reorganization is still in process of development; and it is now advocated by the Wintershall group of producers that only the best mines be permitted to operate, inasmuch as a few of these, if operated at capacity, could supply all the potash now required by domestic and foreign business. Under the present arrangement, 53 shafts were closed down voluntarily until 1953, in the meantime, however, retaining their quotas. With an additional 100 shafts closed temporarily, at the end of 1924 only 70 shafts were in operation; and it is estimated that from 40 to 50 of these could produce the total of all the shafts as operated under the old régime.

It is obvious that great economies could be realized through thus operating the best mines at full capacity, under a system of intensive production, with the elimination of the great overhead represented by the operation of many shafts at low capacity. Advocates of the new régime claimed that if they were permitted to bring about this reorganization to the extent desired, potash could be placed in the American market at 35 per cent less than the present price and still at a profit to the producers.

Listed also as a factor inducing a lowering in prices is the consideration that with potash selling at a low figure the less efficient mines would be compelled to close—an alleged expedient which apparently has been quite effective.

BY-PRODUCTS

One part of the reorganization taking place in the German potash industry, and a part to which considerable emphasis has been given, is the further development of by-products from the refining of crude potash salts. Formerly the tendency was to ship salts in the crude state, but the growing scarcity of high-grade salts had already promoted the application of concentration methods. Even the crude methods of refining formerly applied resulted in large volumes of waste materials, particularly magnesium salts, which proved an embarrassment rather than an asset. While rock salt, Glauber's salt, magnesium sulphate and bromine have been produced as by-products, the equivalent of some 800,000 tons of magnesium chloride has been thrown away annually. Chemical research has been applied to methods of employing larger quantities of this material in industries, notably in the manufacture of plastics, cement, "Steinholz," hydrochloric acid, magnesia, and, potentially at least, in metallurgy in the manufacture of magnesium for light magnesium alloys. New plants of large capacity are now under construction and will soon be in operation, to effectuate this conservation on an enlarged scale. These are activities, prompted by considerations of industrial efficiency, which, it is predicted by their proponents, will result in materially cheapened potash.

During the period when French occupation of German territory deprived the potash industry of its usual supplies of coal, the use of lignite was adopted as an alternative to suspending operations. It was found to be an acceptable substitute for coal, and its general use within the industry now results in a material reduction in the production costs

of the concentrated potash salts below that formerly obtaining.

FRENCH COMPETITION

The desire to meet the competition of the Alsatian mines would furnish an added argument for reduced prices. This competition is formidable out of proportion to the number of shafts operated, since the Alsatian mines are no longer under Syndicate control and are free to operate at full capacity instead of in conformance with Syndicate allocation. Moreover, they enter the world market on a preferential basis by virtue of the more influential position of the French Government, with which the Alsatian industry is closely allied.

AMERICAN COMPETITION

Of especial importance among possible reasons why the price of potash should be depressed was the necessity of eliminating the American industry. This industry had developed during the War to the point where 25 per cent of domestic requirements was actually being produced and where production capacities had been increased to 50 per cent of domestic requirements. Its development threatened the European industry with the loss of its most important foreign market. The American industry had developed in response to greatly increased prices offered for potash, but it was not apparent to what extent it would be able to continue to function after prices had been reduced to the normal. The sudden decline in prices following the reappearance of European potash on the American market was effective in closing the great majority of the American potash plants. The effort of American potash producers to protect their industry against this unrestricted competition by the well-known American expedient of a protective tariff—the most effective argument against such a tariff being that the farmer could obtain cheap potash from

Europe—constituted a further excellent reason for offering potash at the lowest figure known in the history of the industry.

In France also, conditions were such as to induce price reductions to meet American competition. There the inflated franc served to facilitate that objective as did the inflated mark in Germany, and competition with Germany made it necessary to sell at reduced prices. In addition there was the alleged governmental subsidy which, if authentic, would serve in the same direction.

FUTURE PRICES

That it will be possible for Europe to maintain the present low prices is open to doubt. The agreement between the German and French producers, eliminating the competition between them, has been accompanied by a gradual rise in wages, both of these conditions tending to induce increased prices. However, contracts entered into before the consummation of the agreement are not affected, and new contracts drawn up under the agreement are at the prices formerly obtaining.

THE PRESENT ECONOMIC SITUATION WITH RESPECT TO EUROPEAN POTASH

The greatest factor at present influencing the sales price of European potash is the domination of the German potash producers by the French. This has resulted from the past conflict between the French and German industrialists. The trend has been toward the alliance of certain German industries with the French, and it may end by their incorporation into the French economic system. This alliance, which has now extended to the potash industry, will certainly not result in a lowering of the sales price of potash. Competition with the Germans in potash production has proved too irksome. The division of the American market

between the Germans and the French in the ratio of 2 to 1 was the first result; the division of the world market, the second. Competition between the German and French industries, a condition to which the world looked for cheaper potash and the destruction of monopoly, is not and will not be realized.

In the present European situation, there is little that can be interpreted as promising cheaper potash, or in fact the continuance of cheap potash. There is the prospect that potash will have to be increased in price after the present period of adjustment; and it appears that a monopoly, or at least potash dominance by one international combination, has been restored. There is the prospect that we shall have to deal in the future with a French-German monopoly where in the past we dealt with a German. There is no promise that the American farmer will be any better off under the latter than he was under the former. It will require the equivalent of the close coöperation between operators, government, and merchant marine that formerly existed in Germany, to maintain conditions as good as those formerly existing.

Particularly, there is nothing in the European situation that promises to relieve American agriculture from the threat of unrestricted exploitation by foreign potash interests.

To cut us off entirely from our European supply of potash, as was done in the last war, will not now be so easy. It will now be necessary to blockade two nations, where before it was necessary to blockade only one. Two embargoes will now be required, where one was effective before. At the same time the menace is just as great that in the absence of freedom of the seas we may again be cut off from our potash supplies. This is an intolerable state of affairs and one which must be terminated by the development of our domestic potash industry to a point where it is capable of offering an effective defense against such eventualities. At the very least, the domestic industry must be capable of (1) the production of sufficient potash at all times to main-

tain the peace-time prices at a level which will mean only fair profits to the foreign producers, and not exploitation of American agriculture by foreigners, and (2) production in such a way and from such materials that in case of war it can prevent a serious shortage while the industry undergoes an immediate development to the point where the nation's full requirements in potash will be met.

THE AMERICAN POTASH INDUSTRY

FOREWORD

AMERICAN potash investigations were inaugurated at a time when the American farmer was drawing his potash supplies conveniently from Germany, through a well-organized and highly efficient German potash organization. The service was excellent, but the American was given to understand that he was at the mercy of the organization and was receiving only that consideration which a foreign monopoly chose to accord him. Gentle treatment, it was understood, was to be meted out during that period when he was receiving his education in the use of potash; but there was no assurance that at the end of that time he would not be exploited in the manner and to the degree made possible by the vast powers of the Potash Syndicate.

To forestall any such exploitation, as well as to provide against emergencies, such as blockades or embargoes, American investigations of domestic potash resources were undertaken. The latter possibility, a war-time embargo, has materialized, and we have survived it at great cost and inconvenience. Our worst fears in that respect have been realized; our lesson has been learned. Exploitation yet awaits us, and we can avoid it only by finishing the task we have undertaken of establishing our own potash industry.

Activities in connection with American potash may be divided into three periods. It will be recalled that, during the period beginning in 1910 and ending with the inauguration of the Great War in 1914, the potash work done by the Government, through its agencies, the Bureau of Soils and the Geological Survey, in collaboration, had to do principally with reconnoissance surveys of the United

States for possible sources of potash. The succeeding period, represented by the four years of the Great War, was devoted to the development by private interests of practically all the sources of potash discovered and surveyed by the Government. The results obtained during this period are indicated by the accompanying table showing war-time domestic potash production. The third period, represented by the time that has elapsed since the termination of the War, has been one during which the complete deflation, so to speak, of the potash industry has taken place, and during which all of the potash industries established during the preceding period have been subjected to the most trying economic test to see whether or not the raw materials on which they were based and the processes they employed are feasible for peace-time conditions.

The following table gives the quantity and value of the potash produced from these various sources during the war years.

TABLE XV

DOMESTIC PRODUCTION OF POTASH IN THE U. S., 1915-1922, INCLUSIVE

| Year | Crude Potash, Short Tons | Content of Potash (K_2O), Short Tons | Value |
|------|-----------------------------|--|-------------|
| 1915 | 4,374 | 1,090 | \$342,000 |
| 1916 | 35,739 | 9,720 | 4,242,730 |
| 1917 | 126,961 | 32,573 | 13,908,577 |
| 1918 | 207,686 | 54,803 | *15,839,618 |
| 1919 | 116,634 | 32,474 | *11,271,269 |
| 1920 | 166,834 | 48,077 | *7,463,026 |
| 1921 | 25,485 | 10,171 | *447,859 |
| 1922 | 25,176 | 11,714 | *463,512 |

* Value of amount sold.

During this period the American sources of potash which were placed under development were, principally, the brines of the Nebraska Lakes, Searles Lake, Salduro Marsh, and

Great Salt Lake; kelp; cement dust; blast-furnace dust; Steffens waste; distillery waste; alunite; leucite; green-sand; Georgia shales, and wood ashes.

It will be observed that domestic production reached a maximum of about 55,000 tons actual potash in 1918. In this connection it should be stated that at that time additional and enlarged plants were about to be put into commission which would have doubled this amount. It may therefore be said with fair accuracy that we had developed a producing capacity of approximately 100,000 tons actual potash.

With the reappearance of German potash on the American market, American potash industries for the most part, but with important exceptions, suspended operations.

With such a background of large-scale activities—surveys, experimentation, and economic and industrial try-outs—we are now in excellent position to proceed with a comprehensive assay of America's resources in potash. We have at our disposal such a great fund of information that we can now proceed to the development of our industry, knowing definitely what the problems are and in what rests their solution.

Among the conclusions which may be drawn is the definite one that potash produced from known American sources must be yielded as a by-product, or with by-products, if it is to compete with foreign potash. The reason is obvious: it must be produced at a lower cost than is possible if it is to be produced alone from any of the raw materials so far exploited. Therefore, it is essential that the potash problem be attacked from the view-point of obtaining, with the potash, other products of commercial value.

If it were true that we had in America deposits of potash which could be profitably exploited for potash alone, and if those deposits were by nature exhaustible, it would doubtless be the better part of wisdom to permit them to lie undeveloped and in reserve for emergencies, and in the meantime purchase our requirements from the large foreign sources.

But it happens that in America potash is being liberated in tremendous quantities as a side-product of industries already well developed, and is being thrown away and thus permanently lost, and that from such sources it can be advantageously recovered. To conserve this potash and apply it to American agriculture, instead of the imported article, is a procedure which commends itself strongly and constitutes a conservation distinctly worth while. It is an answer to the question: "Why attempt the establishment of an American potash industry while foreign potash may be so cheaply gotten?" The counter question may also be asked: "Why go to Europe for potash while we are throwing away enough to supply domestic requirements?"

The present problem, accordingly, is one of by-products—either the potash must be a by-product or it must be produced simultaneously with by-products. Preferably, it should be produced as a by-product of industries already established. If it is to be produced with the accompaniment of by-products, the latter should be commodities which are already familiar to their prospective purchasers, and for which a market already exists.

Each source here described constitutes a separate problem. Steffens waste (the residue from beet-sugar manufacture) and distillery waste (the residue from fermented molasses), having a somewhat similar origin and composition, may be processed by somewhat similar methods; and an analogous statement may be made with regard to cement and blast-furnace dust. Each source will be discussed in its appropriate order.

POTASH FROM KELP

Early in the investigation of American potash, particular attention was paid to the so-called giant kelps, or seaweeds, of the Pacific Coast, which had been found to carry high concentrations of potash salts. Reconnaissance surveys of the areas of growing kelp revealed a very large tonnage available. Subsequent and more exact surveys showed

that these marine plants were easily accessible, as an annual crop, in such quantities as to supply a considerable portion of the potash required for American agriculture.

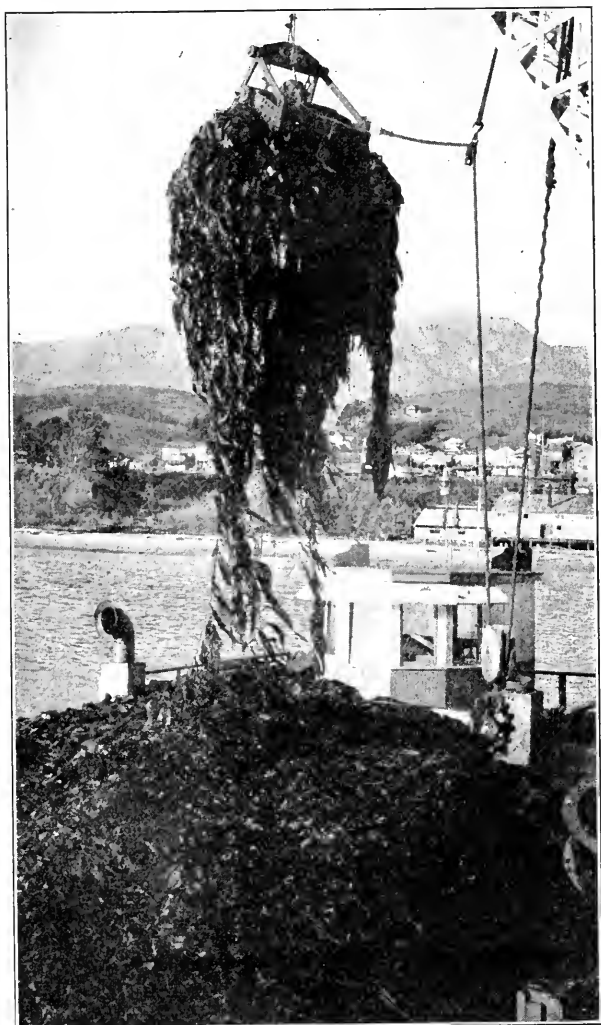
EARLY INVESTIGATIONS

Preliminary laboratory investigations of kelp showed that it was capable of yielding, together with potash, a number of by-products such as iodine, ammonia, and various tar products. It was believed that there was a distinct possibility of working out a process whereby all of these products, and possibly additional ones, could be manufactured in such a way as to yield a profit, more than sufficient to cover the cost of producing potash, and thus enable kelp potash to enter the market in successful competition with the German article. Inasmuch as kelp offered a longer series of by-products than any other potash-bearing material so far investigated, and was not under private development, plans were prepared for an experimental and demonstrational plant to be erected on the Pacific Coast. Preliminary estimates, based on laboratory results, were made up of costs for labor, freight, and commodities as they obtained during the pre-war period. No enormous profits were anticipated, but estimates warranted experimentation on some commercial scale.

KELP PRODUCTS PLANT OF THE BUREAU OF SOILS

A plant was begun in February, 1917, at Summerland, Calif., and was put into operation in August of that year. The plans contemplated a plant of the smallest capacity that would still make possible the establishment of data which could be said to apply to the manufacturing scale. It was the ambition of those in charge to put the plant on a self-supporting basis, thus making the products pay the cost of the experiments. Because of the constant falling off in the price obtainable for potash, from the high point obtaining

at the time of the inauguration of the experiments, and the constant and rapid increase in the cost of labor, trans-



Unloading Kelp from Harvester at Governmental Experimental
Kelp-Products Plant

portation, and commodities, this goal was not reached until the last months of operation of the plant. However, sub-

stantial revenues were realized throughout the period from the sale of products.¹

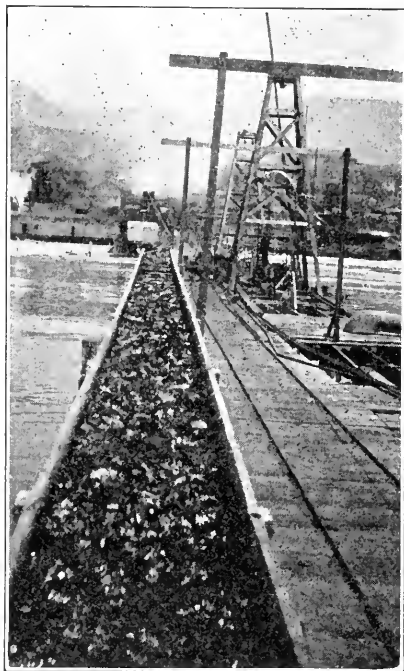
The experiments inaugurated in 1917 were terminated in 1921. During this period methods of processing kelp were devised, developed, and inaugurated as plant-scale processes. Kelp was harvested, dried, subjected to destructive distillation, and leached to remove its water-soluble constituents; and the water solution so resulting was evaporated for the crystallization of potash salts and recovery of iodine. The charcoal residue was treated to convert it into an active and valuable bleaching agent. Three products, potash salts, iodine, and decolorizing carbons, were placed on a full manufacturing basis; the capacity of the plant in all three departments was raised to the basis of 100 tons raw kelp per day. Full cost data covering the various operations were secured; ammonia and tar derivatives—such as various oils of interesting properties and potential value, creosote, and related materials—were shown to be commercially available, and processes were developed for their manufacture. With the three products, potash, iodine, and decolorizing carbons alone, it was shown that, even in a small plant such as this, substantial profits were obtainable; it was thus made evident that in a larger plant, built according to plans and using improvements in processes developed here, an industry of size and importance and of great usefulness to the Nation could be established, a raw material, large in extent, inexhaustible, and totally unutilized, could be made of use, and substantial profits could be realized.

BY-PRODUCTS

The potash, which was at first the main product and was the one around which the original plans were developed,

¹ For a more detailed account of this work, see the series of articles entitled "Potash from Kelp" I-VIII, which have appeared in *J. Ind. Eng. Chem.*, Vols. 11-16, incl., 1919-24.

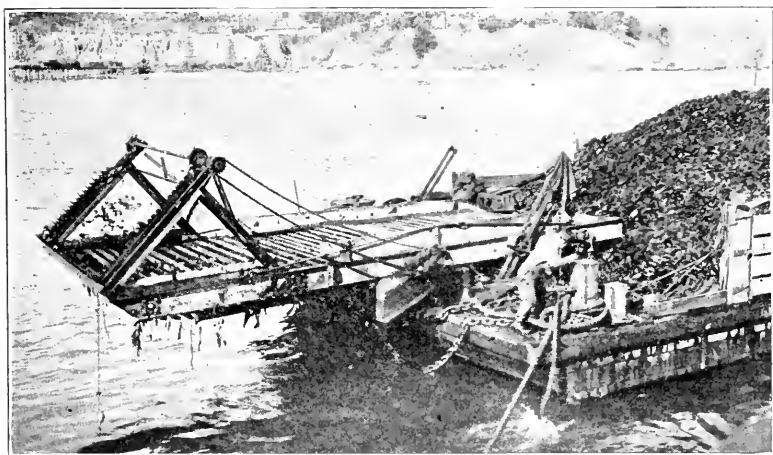
was forced into the position of a by-product by the discovery that the charcoal residue remaining after the extraction of potash could by a simple treatment be converted into an active bleaching or decolorizing and purifying carbon, useful as a substitute for bone black and in demand in many industries. The great value attached to this product gave it



Conveying Kelp from Harvester to Storage Bins.

first place in the order of consideration. All of the energies of the research organization were turned to its development. A process of manufacture was devised and put into practice which made it possible to produce the decolorizing carbon at a very low cost, thus enabling this one product to bear the main items of expense involved in the entire process for the manufacture of kelp products. Since the carbon came to be considered the main product and was so regarded in

the computation of cost data, potash and iodine became by-products. This gave potash a very strategic position indeed, from the point of view of competition with the foreign article. On the basis of cost data as computed here and in a plant large enough to justify the utilization of full capacity, standard apparatus, and labor-saving devices, the decolorizing carbon can be made to carry practically all of the manufacturing costs involved, leaving potash, iodine, ammonia, and other products to carry only those items of cost involved in their final manipulation.



Kelp Harvester with Load of Kelp, Governmental Experimental Kelp-Products Plant.

Decolorizing Carbon.—The decolorizing carbon manufactured from kelp has been applied to a long series of products in a great variety of tests on an experimental, semi-plant, and full-plant scale, and has been found to be an especially useful and valuable reagent. It was marketed under the trade name of “Kelpchar,” and won great favor. It has been successfully applied to the bleaching of cane and beet sugar, malt syrup, glucose, and syrups from various other sources; organic acids such as citric, lactic, tartaric, acetic, and malic; glycerine; inorganic acids; edible and

non-edible vegetable and animal oils; various petroleum products; dye intermediates; refined chemicals, pharmaceuticals, and photographic chemicals. As manufactured for the trade, it is of a grade of activity comparable to that of the best carbons on the market. But a process of manufacture was inaugurated which made it easily possible, when desired, to increase this activity to a much higher point, equaling four times that of the best commercial carbon at that time obtainable on the market. It is remarkably free-filtering, affording rapid filtration and a clear filtrate. It can be prepared as free from water-, acid-, and oil-soluble constituents as would be required by the most exacting market, and its cost of manufacture is such as to guarantee for it successful competition with other carbons of equal activity. It can be reactivated repeatedly and used over and over again, a fact which must be given full consideration in the computation of cost data pertaining to its use.

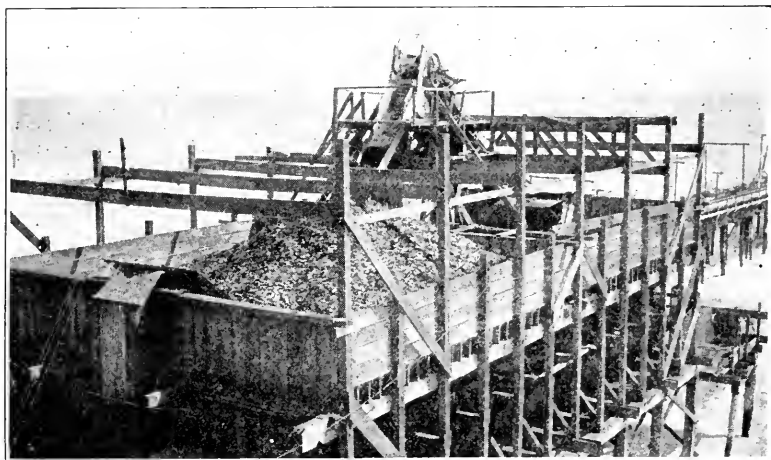
Potash.—The potash normally yielded by the simplest process here developed was potash of the fertilizer grade, 80 per cent muriate. Its impurities were principally potassium sulphate and sodium chloride. Thus, it is comparable to the standard fertilizer grades of potash obtainable on the market, is superior to most of the European products, and is entirely free from all impurities which, from the point of view of the fertilizer industry, can be regarded as in the least deleterious.

Since hydrochloric acid is a reagent required for best results in the manufacture of Kelpchar, a properly equipped kelp-products plant will be provided with facilities for converting the muriate of potash into sulphate or phosphate, with the manufacture of dilute hydrochloric acid for use within the plant. This will not only decrease the cost of manufacturing Kelpchar, but will increase the value of the potash and make it available for agricultural use under the most exacting circumstances, particularly in the western markets where the farmers have been prejudiced through propaganda against the use of muriate. Kelp plants, from

their nature, will be situated on the seaboard; kelp potash accordingly will gain the advantages of water transportation.

Processes have likewise been worked out whereby chemical grades of muriate of high analysis can be prepared simply and with only a slight advance in cost over that of the fertilizer grade, affording a further source of chemical potash for American industries.

Iodine.—The iodine produced from kelp can be easily prepared in any grade exacted by the trade and in substantial quantity. For this commodity America is still entirely



Kelp Storage Bins.

dependent on foreign sources—principally Chile, although the Japanese have developed a kelp-iodine industry which makes it possible for them to export considerable quantities. The fortunes of the iodine industry of Chile are entirely involved in the nitrates industry, and rise and fall with that industry. Any combination of circumstances which will operate to close down or seriously depress the prosperity of the Chilean nitrate industry will deprive the world of its main source of iodine. This is a commodity essential to important American industries, of wide application in the arts and sciences, and is one of which America may be de-

prived at any time so long as she is dependent on a foreign source. The kelps of the Pacific offer a prompt and satisfactory alleviation of this undesirable state of dependence.

Since the kelp-products industry in its present stage of development is based on the manufacture and sale of Kelpchar, the extent to which by-products can be manufactured from kelp depends on the market for Kelpchar. It is entirely possible that further developments will yield processes which will alter this situation so that even larger quantities of potash and iodine can be produced economically and without regard to the present limiting condition.

ANALYSIS OF KELP POTASH

The process described lends itself readily to the preparation of a fertilizer grade of potash, obtained as a direct product without any effort at purification. This is an 80 per cent potassium chloride, entirely comparable to the high-grade muriate found in the fertilizer trade. The process may be easily modified to yield a chemical grade of potash. This is no more valuable, however, from the point of view of the fertilizer industry, except in that it may be transported at a lower rate per unit.

In the following table is shown the analysis of 80 per cent kelp potash.

TABLE XVI

ANALYSIS OF POTASH FROM KELP, FERTILIZER GRADE

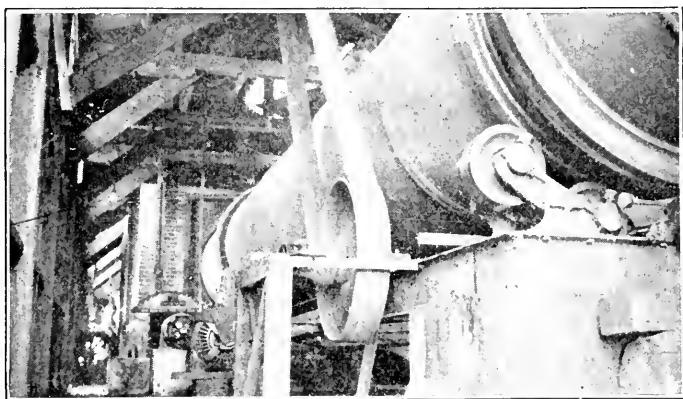
| | Per Cent |
|--|----------|
| Potassium chloride (KCl)..... | 81.0 |
| Sodium chloride (NaCl)..... | 3.0 |
| Sodium sulphate (Na_2SO_4)..... | 9.2 |
| Sodium carbonate (Na_2CO_3)..... | 3.5 |
| Water..... | 2.5 |

OTHER KELP PROCESSES

The high price obtainable in war-time for potash prompted the establishment of various kelp plants for the extraction

of potash alone. As the fertilizer industry represented the principal market, potash of fertilizer grade was the objective. For this purpose kelp was harvested by marine harvesters—which worked with marked efficiency, delivering kelp in hundred-ton lots at moderate costs per ton—and was dried in direct-heat rotary kilns and subsequently burned to an ash. This yielded a product containing about 30 per cent actual potash.

In one plant, that of the Diamond Match Co., where high-grade potassium chloride designed for chemical use



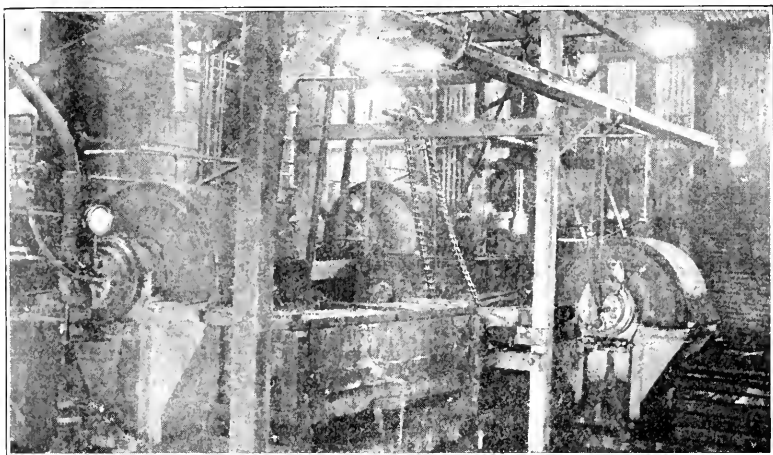
Rotary Kelp-drying Kiln.

was the objective, this ash was leached and the resulting brine evaporated for the crystallization of potash salts.

The organic constituents of kelp, containing a considerable percentage of nitrogen, offered an opportunity for the production of agricultural ammoniates. In one important instance, in the plant of the Swift Fertilizer Co., this nitrogen was conserved by preparing the thoroughly dried kelp to be used directly as fertilizer. The product contained 15 per cent actual potash and about 3 per cent ammonia.

A more complete utilization of the organic constituents of kelp was accomplished by The Hercules Powder Company, a corporation engaged in the manufacture of explo-

sives, which utilized kelp as a fermentation medium for the manufacture of acetone. The sugar-like constituents, or polysaccharides, of kelp, when subjected to fermentation by natural yeast, yield, for the most part, acetic acid, which is convertible into acetone. This process, like the one previously described, led to the formation of a series of by-products, in this instance organic acids of the acetic series, aldehydes and ketones. These, in the competent hands of a large staff of research chemists, were developed into an imposing line of by-products, of a great variety of useful



View in Kelpchar Department.

applications. Finally, the residual solutions were evaporated for the manufacture of potassium chloride of chemical grade, and iodine.

This plant, with a daily capacity of 1500 tons of raw kelp, afforded an important illustration of American chemical ingenuity. It closely approached the solution of the problem of the utilization of kelp as a raw material for the profitable manufacture of a long list of valuable chemical compounds, both organic and inorganic.

Among the organic constituents of kelp is a material known as algin, to which a good deal of profitable study has

been devoted in the past. This product possesses properties which give it great interest and potential value as a plastic, adhesive, filler, and sizing, and in related applications. It might easily become the basis of an important kelp-products industry. Present and proposed methods of manufacture do not show that potash and iodine will become immediate by-products of such an industry, but future researches may disclose methods for accomplishing that desirable end.

The conservation of the potash and iodine of the kelp used in this way is so important that it will eventually be realized. In initiating the industry, therefore, provision should be made in both process and plant for the recovery of these by-products, as such provision can be more economically made in the beginning than after the industry has become established. The rewards will justify the initial expense.

QUANTITIES OF KELP AVAILABLE

The Bureau of Soils, in 1912-1913, made surveys of the areas of growing kelp in American waters from the Mexican border northward and westward to the Alaskan Peninsula.¹ The various groves were mapped and measured, and the quantities of kelp which they contained were estimated. These surveys were serviceable in calling public attention to the enormous perennial supplies of this valuable raw material, at that time wholly unutilized, and in pointing out favorable plant sites for its utilization.

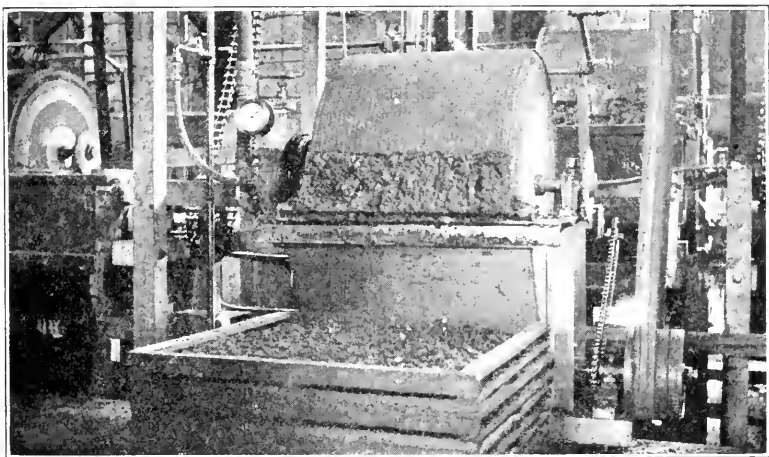
During the war years, when the kelp groves, particularly those of the waters off Southern California, were being actively harvested, the opportunity was offered for observing the yields actually obtained under working conditions. These observations were continued over several seasons and the results published as a part of the report of the late Dr. R. P. Brandt.² They pertain only to the groves of

¹ "Report 100," Potash from Kelp," by Cameron *et al.*, U. S. Dept. Agri. 1915.

² "Potash from Kelp. Early Development and Growth of the Giant Kelp, *Macrocystis pyrifera*," Brandt and Turrentine, Dept. Bul. 1191, U. S. D. A.

Macrocystis pyrifera of Southern Californian waters. This species being a perennial, several crops a year may be harvested.

The records show that for the two years 1917 and 1918 the years of most intensive kelp operations, the annual crop was approximately 400,000 tons. This quantity was obtained from the larger commercial beds under conditions of competitive cutting, before State regulation was instituted, conditions which were not conducive to efficient mariculture. Accordingly, this quantity is not taken to represent



Kelpchar Filter.

the maximum obtainable from this territory and no effort will be made to estimate that maximum. But, on the basis of observations there made, the figure of 500,000 tons per annum may be taken as a very conservative estimate of the raw material available in that district.

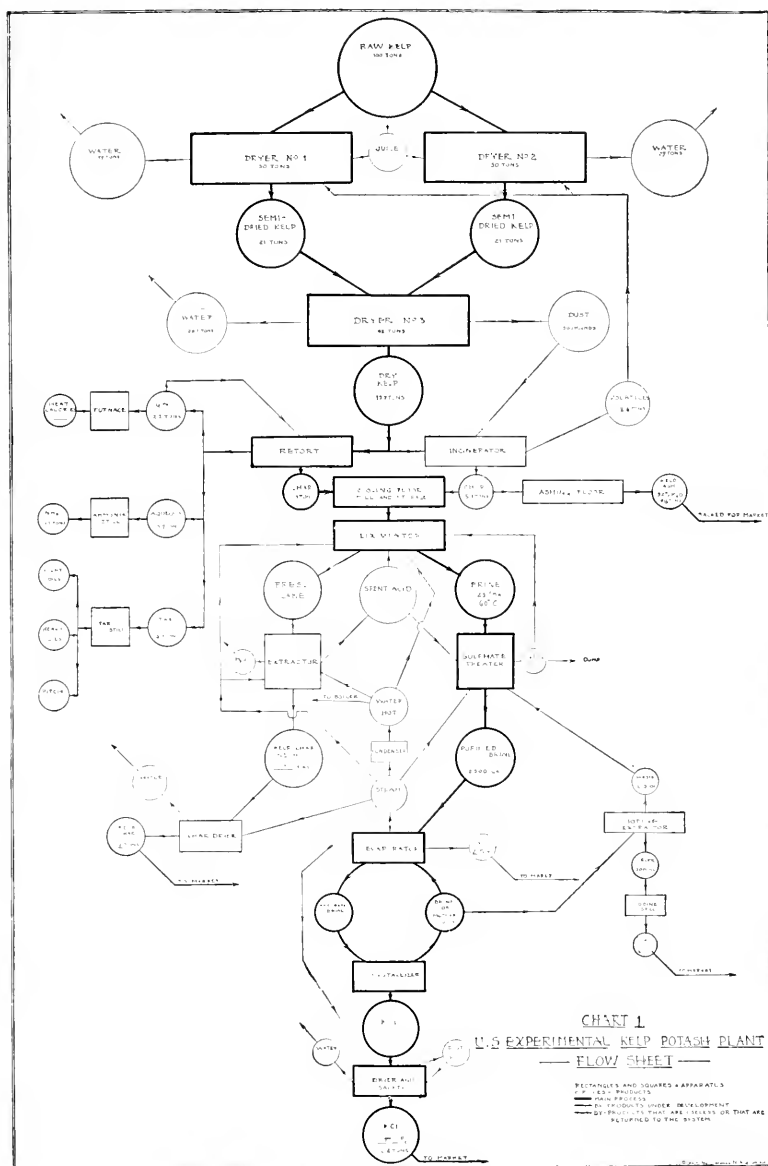
As raw kelp contains about 1.5 per cent potash, this quantity is equivalent to 7500 tons actual potash. Other districts, such as the Puget Sound and the Alaska areas, provide additional large annual crops. Altogether, therefore, the Pacific kelps are capable of yielding important quantities of potash.

Here again, however, the potash must be yielded as a by-product or as a side-product with decolorizing carbons, iodine, ammonia, acetone, or algin, and the quantity which can be produced from this raw material will be determined by the market for these other products.

AMERICAN IODINE

America is now entirely dependent on foreign sources for all of the iodine used here in the various arts and industries. That commodity is an essential in certain chemical industries. Moreover, it is now recognized as an essential article of diet if the populace is to be kept free from goiter. The natural supplies obtainable in the food materials produced over large areas of the country are not sufficient to keep the people in a normal state of health. A large portion of them are suffering from iodine deficiency, manifesting itself in various forms of goiter and other thyroid disorders. To remedy this deficiency, manufactured iodine compounds, prepared from imported iodine, are being widely used. The kelps commend themselves as a convenient source of natural, organic iodine for meeting this serious dietary deficiency.

The world's supply of this essential element is now obtained from the Chilean nitrate beds, where iodine is yielded as a by-product of the nitrate industry, while a small additional supply is gotten from the Japanese kelp industry. It does not appear to be wise to permit this state of dependence to continue indefinitely. At any time this single supply may be cut off, with serious results ensuing. Kelp is our only known domestic source of iodine. Some basis for a kelp-iodine industry should be established within these borders. The character of that industry should be such that through it the technology of the recovery of iodine from kelp could be standardized, and from it an industry, capable of supplying our emergency needs if not our normal requirements, could be immediately developed.



Flow Sheet of Kelp-Potash Process.

It should become a part of any comprehensive plan of national preparedness and industrial and economic independence to provide adequate supplies of iodine for any national situation that might arise.

POTASH FROM SURFACE BRINES

In a search for deposits of soluble potash salts, two sorts of deposits may be anticipated: those of marine origin, as typified by the German deposits, resulting from the evaporation of great volumes of sea water which have been cut off from the main body of the ocean through the formation of bars or reefs; and those of inland or continental origin, typified by the various salt lakes and surface saline deposits resulting from the evaporation of inland seas or lakes.

Within the United States, deposits of salines of the latter sort are numerous and well known. That there may be deposits of the former variety is strongly indicated by the enormous deposits of rock salt occurring in various localities, and particularly by the deposits of polyhalite, typical of marine deposits, recently discovered in Texas; but the purity of the salt deposits in other regions, notably in Louisiana and New York, suggests other origins.

NEBRASKA LAKE BRINES

The lakes occurring in the western part of Nebraska are small, shallow bodies of water containing varying concentrations of potassium and sodium salts. They are scattered over an area of about 800 square miles and in no instance contain a very large volume of brine. The actual quantity available, however, is very much larger than is at first apparent, since it has been found that additional volumes are contained in underlying strata, adding greatly to the total. The brines contain 2 to 12 per cent solids, the composition of which may be illustrated by the following analysis of a sample from Jesse Lake, the best known and most concentrated of the lakes.

TABLE XVII

COMPOSITION OF TOTAL SOLIDS CONTAINED IN A SPECIMEN OF JESSE LAKE BRINE *

| | Per Cent |
|---|----------|
| Potassium sulphate (K_2SO_4) | 26.5 |
| Potassium carbonate (K_2CO_3) | 21.5 |
| Sodium carbonate (Na_2CO_3) | 36.5 |
| Sodium bi-carbonate ($NaHCO_3$) | 9.2 |
| Sodium chloride ($NaCl$) | 5.8 |
| Insoluble | 0.2 |
| Total | 99.7 |

* "The Potash Industry of Nebraska," Condra.

WAR-TIME ACTIVITIES

In the governmental investigations of American potash the Nebraska lakes were early recognized as a source of this material, but were regarded as being too small in volume to warrant giving them any great prominence as a permanent source. War-time emergencies justified their exploitation, however, and their relative closeness to the market made the more concentrated ones a logical and valuable source of potash. They were promptly placed under development and made a very substantial contribution to the American supplies of this essential commodity throughout the war period, supplying more potash than any other one source. During this period about twenty-five plants were erected, the larger having a daily capacity of 200 tons of crude potash. In 1918 they produced over 116,000 tons of salts, equivalent to 29,000 tons of actual potash. Brine was collected from many lakes and delivered to the plants by means of an extensive system of pipe lines. The brines were concentrated in single- or multiple-effect evaporators and finally evaporated to dryness in direct-heat rotary kilns. The product, without further refining, was ground and shipped to market.

Under war-time impetus this field was greatly overdeveloped. The number of plants erected was greatly in

excess of the logical number; excessive competition resulted in the evaporation of brines of very low concentrations. As these plants were maintained by war-time conditions, it was unfortunately inevitable that with the passing of these conditions they would have to suspend operations. This eventuality was promptly realized on the termination of the War.

VALUE OF NEBRASKA POTASH LAKES

This field could probably be exploited successfully in times of peace if a number of conditions were realized. These conditions include the elimination of competition and of excess plants in this field, the institution of unified control, the proper management of the various bodies of brine, the application of solar evaporation to eliminate the excessive evaporation formerly required and carried on artificially, the delivery of highly concentrated brines exclusively into the plants for final evaporation, and the development of by-products. The application of highly developed technical operations, however, must of necessity supplant haphazard methods designed exclusively for quick results and without due regard for manufacturing costs. At best, however, the field is limited in the total quantity of potash it is capable of producing as there seems to be no inexhaustible source of potash from which to maintain for an indefinite period any high concentration in the lake brines. Various theories have been offered to account for the potash here present, but none of them hypothesizes any great ultimate source. These lakes cannot be regarded, therefore, as an inexhaustible supply of potash, but under conservative exploitation they are capable of making a valuable contribution to the nation's potash supplies. As an emergency source of potash they have real importance.

QUANTITY OF POTASH AVAILABLE

The exploration of the field having revealed potash brines in the sandy strata underlying the lakes at a depth of about 12 feet, these became the chief source of brines for potash extraction. These conditions were found in an area of about 800 square miles, but were found to vary greatly from place to place. Some brine was found in valleys possessing no lakes. The quantities available are therefore difficult to determine. However, it has been estimated by Hicks,¹ who made an examination of the region, that the area might be found to contain a volume of brine containing one per cent of potash or better, equivalent to several hundred thousand and possibly half a million tons of actual potash.

During the war period, the only product shipped was crude salts representing total solids of the brines evaporated. This fact connotes high freight rates per unit of potash, and absence of by-products. Both considerations demand research to determine the most advantageous methods of preparing the potash in a higher state of purity, and of utilizing the impurities for the manufacture of useful by-products. Here is a problem offering the distinct promise of an affirmative solution. Its solution would have an immediate and very favorable effect upon the economic aspects of this potentially valuable source of potash. In being conveniently situated with respect to a large agricultural area, this field already enjoys an important natural advantage.

The quality of the potash produced by the Nebraska plants was good. The impurities, while somewhat objectionable from the point of view of fertilizer technology, were favorable from that of plant nutrition. Being alkaline in nature, they would tend to liberate ammonia from certain combinations in mixed fertilizers. At the same time, a

¹ W. B. Hicks, "Potash in 1918," U. S. G. S.

limited amount of mild alkalinity may be of distinct advantage in fertilizers that are to be applied where it is desired to prevent or correct soil acidity. The following analysis may be taken as typical of the potash from this source:

TABLE XVIII
ANALYSIS OF POTASH FROM NEBRASKA LAKES

| | Per Cent |
|---|----------|
| Potassium sulphate (K_2SO_4) | 34.61 |
| Potassium chloride (KCl) | 8.99 |
| Potassium carbonate (K_2CO_3) | 1.33 |
| Sodium carbonate (Na_2CO_3) | 55.07 |

CONTINENTAL DEPOSITS

On account of their supposedly greater accessibility, more study has been devoted to the search for continental deposits, there being abundant evidence of the former presence of great inland seas which, because of evident barriers which prevented their seaward drainage, must have disappeared through evaporation. Any salts held in solution must therefore have been deposited as desiccation products.¹

These researches have been confined to the undrained basins of the western part of the United States. Since those basins have not been filled by detrital material, it was hoped that potash deposits would be found on their original bottoms, only moderately deeply covered with recent detrital depositions, and within easy reach of the present surfaces. The few shallow borings so far put down, however, have failed to locate in these regions any important crystalline segregations of potash salts. The potash deposits here found have been largely surface deposits, for the most part represented by lakes of natural brines and salt crusts and marshes.

¹ Cf. E. E. Free, "The Topographic Features of the Desert Basins of the United States with Reference to Possible Occurrence of Potash," Dept. Bul. 54, U. S. D. A.

THE BONNEVILLE BASIN

In northwestern Utah and extending across the borders of that state into eastern Nevada, is an undrained basin, a topographic unit formerly occupied by a great Quaternary lake to which the name Lake Bonneville has been given. The last remnant of this inland sea is the present Great Salt Lake. As this lake is set in Paleozoic sediments, the salines carried into it would be neutral salts, mainly the chlorides and sulphates of sodium and magnesium, as is supported by the composition of the brines of Great Salt Lake and of salt marshes and subterranean brines from this region.

It might be concluded that potassium salts were present in Lake Bonneville only in low concentrations, a conclusion given some substantiation by the analysis of the brine from its remnant, the Great Salt Lake. To be sure, it is not impossible, in view of our present knowledge, that in some previous era the lake may have become completely dry, depositing the saline accumulations of the preceding ages, and that the salts of the present lake represent the accumulation of a more recent age. The reported presence of potash brines of important concentrations, impregnating strata underlying considerable areas in this region, would tend to cast some doubt on the assumption that the Salt Lake brine is representative of the composition of Lake Bonneville.

SALDURO MARSH BRINE

Salduro Marsh, situated on the Western Pacific Railroad, 110 miles west of the Great Salt Lake, embraces an area of about 125 square miles. In winter this area is covered with brine, and in summer with a salt crust about 3 feet thick. Beneath is a mud stratum of unknown depth, likewise impregnated with brine. For a part of the year the region is one of high aridity and is therefore favorable to solar evaporation.

The following analysis¹ illustrates the composition of the brine here obtainable:

TABLE XIX
SALTS IN THE SALDURO BRINE

| | Per Cent |
|---|--------------|
| Sodium chloride (NaCl)..... | 81.04 |
| Potassium chloride (KCl)..... | 7.03 |
| Magnesium chloride (MgCl ₂)..... | 9.07 |
| Calcium chloride (CaCl ₂)..... | 0.88 |
| Sodium sulphate (Na ₂ SO ₄)..... | 1.98 |
| | <hr/> 100.00 |

It will be observed that this is distinctly a chloride brine. This fact simplifies the problem of the separation of the sodium and potassium by evaporation and crystallization methods. The presence of large quantities of magnesium offers opportunity for obtaining a valuable by-product.

The Solvay Process Co. exploited these brines as a source of potash for war-time requirements and, following unsuccessful attempts to obtain potash therefrom by artificial evaporation and crystallization, developed a highly successful method of accomplishing that recovery by natural solar evaporation. For this purpose, concentric, circular canals were dug in the marsh, and the brine accumulating in these was circulated from the outer canal through the series to the inner, by being pumped over the separating dikes, undergoing evaporation the while. Eventually a concentration was reached at which potassium chloride was deposited. This was prepared for the market in two grades, as illustrated by the following analyses.

The end of war-time potash prices and the reorganization of the activities of the Solvay Process Co. combined to bring to an abrupt end the excellent developments that were taking place at Salduro Marsh. As an emergency source of potash, these brines are valuable; but on account of their relatively limited volume and remoteness from the

¹ Gale, "Potash in 1916" Mineral Resources of the U. S., 1916—Part II, p. 100, U. S. G. S.

present fertilizer market they cannot be looked upon as a very important source of potash for normal and long-time requirements.

TABLE XX

ANALYSIS OF 85 PER CENT MURIATE OF POTASH FROM SALDURO MARSH

| | Per Cent |
|-------------------------|----------|
| Potassium chloride..... | 85.50 |
| Sodium chloride..... | 12.50 |
| Magnesium chloride..... | 0.46 |
| Magnesium sulphate..... | 0.45 |
| Calcium sulphate..... | 0.95 |
| Insoluble..... | 0.50 |

ANALYSIS OF 25 PER CENT MURIATE OF POTASH FROM SALDURO MARSH

| | Per Cent |
|-------------------------|----------|
| Potassium chloride..... | 25.0 |
| Sodium chloride..... | 65.0 |
| Magnesium chloride..... | 4.0 |
| Magnesium sulphate..... | 1.0 |
| Calcium sulphate..... | 2.0 |
| Insoluble..... | 1.0 |

GREAT SALT LAKE BRINE

The brines of the Great Salt Lake, of Utah, have repeatedly been examined as a source of potash. A typical analysis is represented by the following tabulation. It suffices to show the extremely small percentage of potash contained in these brines, and to indicate the difficulties to be encountered in their manipulation for its commercial extraction.

TABLE XXI

COMPOSITION OF GREAT SALT LAKE BRINE (CONVENTIONAL COMBINATION)
SALINITY 20.35 PER CENT *

| | Per Cent |
|---|----------|
| Potassium chloride (KCl)..... | 3.16 |
| Sodium chloride (NaCl)..... | 75.91 |
| Magnesium chloride (MgCl ₂)..... | 10.92 |
| Sodium sulphate (Na ₂ SO ₄)..... | 9.52 |
| Calcium sulphate (CaSO ₄)..... | .34 |
| Calcium carbonate (CaCO ₃)..... | .15 |
| Total..... | 100.00 |

* Sample collected by H. S. Gale; analyzed by R. K. Bailey; cf. Gale, "Potash in 1916." U. S. Geological Survey, 1917, p. 95.

The brine in its natural state is approximately saturated. As is seen from the preceding table, there are about 25 parts of sodium chloride to one of potassium chloride, and the former must be eliminated by crystallization methods before the latter can be isolated. In addition, there are quantities of sodium sulphate and magnesium chloride, both greatly in excess of the potash salt. If these could be marketed as by-products, the prospects of profit would be enhanced. The chemical system here to be dealt with is one that might easily lead to the formation of complex potash salts during crystallization, and thus further complicate the problem. Moreover, where such large quantities of other salts have to be removed from the potash brine, there are likely to be serious losses in values through the adsorption of the potash on the crystals of the other salts. However, a favorable consideration is that of the possibility of employing the modern methods of solar evaporation, the aridity of the district being favorable to that practice.

Notwithstanding these difficulties, two enterprises were inaugurated during the war years to recover potash from this source, the plants respectively of the Diamond Match Co., under the name of the Salt Lake Chemical Co., designed to treat the lake brine directly, and of the Utah Chemical Co., designed to obtain potash from the mother liquors remaining after salt recovery by the Inland Crystal Salt Co. Little has been made known concerning the operations of these companies or the processes employed. But, from what is known of the unfavorable nature of this raw material and its remoteness from the market, it may be concluded that the contribution here made to the solution of the American potash problem, even for war-time emergencies, was of slight importance. The only outstanding consideration of a favorable nature here involved is the enormous supply of raw material readily available.

THE LAHONTAN BASIN

During the Quaternary period of greatest lake expansion, the core of the basin found in northwestern and central Nevada was a single great lake. Its history has been studied by Russell, who gave it the name of Lake Lahontan. The basin is nearly a unit, the divides now evident being low or discontinuous. The old Lake Lahontan is now represented by a few remnants, such as Pyramid, Winnemucca, and Walker Lakes, and by a number of sinks, playas, and saline marshes. The salts now present on its surface are certainly far less than those which may be assumed to have been present in the larger lake, and accordingly it must be concluded that they have been buried by alluvial coverings. It is reasonably certain that the original saline constituents of Lake Lahontan underlie the floor of the present basin, either as crystalline deposits or as salt-impregnated strata of alluvial material.

The rocks of the basin and its drainage area are largely igneous, though, for the most part, non-potassic, from which it may be concluded that the salts present in the lake were largely sodium salts and were alkaline in character. Verification of these deductions awaits comprehensive exploration by borings.

In efforts to draw conclusions relative to the segregation of potash salts, an element of uncertainty is always injected by the fact that the potassium ion has a high coefficient of adsorption and tends to eliminate itself from solution whenever colloidal or finely divided material is present. In bodies of water undergoing desiccation as the result of arid conditions, the presence of suspensions of the finer particles of soil material, washed into the water during seasonal periods of rainfall or intervening eras of humidity, tends to cause the adsorption of the potash on the soil particles and, with the settling out of such suspensions, its elimination. It may be concluded therefore that wherever, from a study of the stratigraphy of the rocks associated with anticipated

potash deposits, it is evident that the process of desiccation leading to the formation of saline deposits was interrupted by periods of freshening—as shown by alternate strata of saline and clayey material—conditions were unfavorable to the segregation of potash salts in the crystalline form.

SMALL BASINS OF SOUTHERN NEVADA AND CENTRAL AND SOUTHERN CALIFORNIA

The region south and southwest of the Lahontan Basin is similarly lacking in seaward drainage and was occupied by lakes during an earlier period. Topographically, the country is divided by high and continuous mountain ranges into a number of small basins, each with its individual characteristics. In this area are included the Mojave Desert, and Searles, Owens, Deep Springs, Saline, Amargosa, and Death Valleys. Their rim rocks are varied and have been but little studied, although it is known that surrounding them lie rocks of both igneous and sedimentary origin and that the basement granites of the Sierra Nevada are exposed in places, particularly toward the southwest.

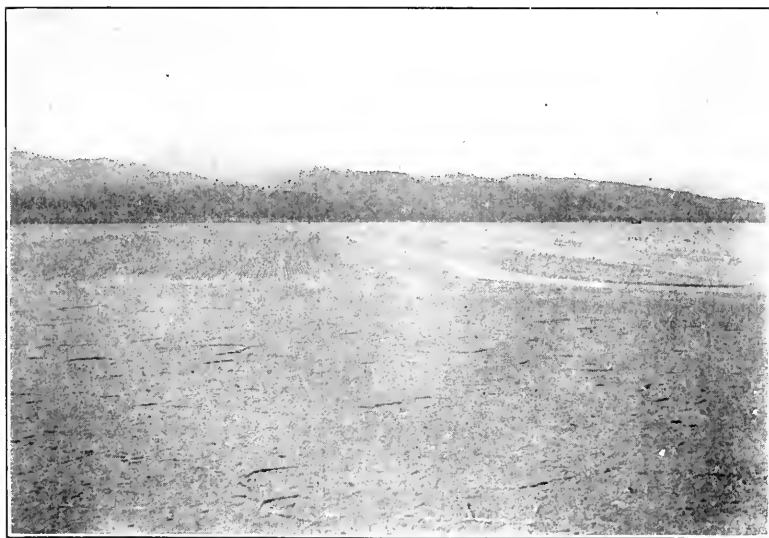
Of especial interest and importance among the basins of this group is Searles Lake. Within the loosely defined strata of salts are here found various crystalline minerals, among which may be mentioned halite (NaCl), thenardite (Na_2SO_4), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), gaylussite ($\text{Na}_2\text{CO}_3 \cdot \text{CaCO}_3 \cdot 5\text{H}_2\text{O}$), borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$), natron ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$), and hanksite ($\text{KCl} \cdot 9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3$).

SEARLES LAKE BRINE

A great deal of attention has been devoted to Searles Lake brine as a source of potash since the discovery of this lake as a potash-bearing body by E. E. Free and Hoyt S. Gale in 1911. At present it supplies the raw material for the largest American potash industry.

Searles Lake, located in the northwestern part of San

Bernardino County, Calif., occupies the floor of a valley which is partially surrounded by hills and mountains. The region is typically desert in nature, with a very light rainfall and the high temperature and strong winds characteristic of desert regions. The lake, itself, is a salt flat occupying an approximate area of 11 square miles. The main salt body is about 60 feet thick, although below this there are alternate strata of mud and salts. The salt body is impregnated with brine, which during certain seasons of the year



Searles Lake, California.

also covers the surface to the depth of a few inches. Most of the potash is contained in the brine, the salt body being made up principally of sodium chloride. However, there are crystalline potash compounds, complex in nature, to be found in some of the salt strata. The brine, of course, is saturated with the compounds which constitute the salt body.

The Searles Lake brine has a density of 1.295 at 23° C., representing a concentration of 34 per cent. Its potash content is about 2.5 per cent actual potash.

The composition of its total salts is represented by the following typical analysis:

TABLE XXII
ANALYSIS OF SEARLES LAKE BRINE

| | Per Cent |
|---|----------|
| Sodium (Na)..... | 33.57 |
| Potassium (K)..... | 6.06 |
| Chlorine (Cl)..... | 37.02 |
| Sulphur trioxide (as SO_4)..... | 12.96 |
| Carbon dioxide (as CO_2)..... | 6.70 |
| Boron tetroxide (B_4O_7)..... | 3.00 |
| Total..... | 99.31 |

CONVENTIONAL COMBINATION

| | Per Cent |
|---|----------|
| Sodium chloride (NaCl)..... | 43.00 |
| Potassium chloride (KCl)..... | 13.00 |
| Sodium sulphate (Na_2SO_4)..... | 20.00 |
| Sodium tetraborate ($\text{Na}_2\text{B}_4\text{O}_7$)..... | 4.30 |
| Sodium carbonate (Na_2CO_3)..... | 13.00 |

It will be observed that, while the most valuable compounds here present are potassium chloride and sodium tetraborate, all of the salts have some commercial value and, assuming favorable economic conditions, are marketable.

QUANTITIES

The total quantities of potash and borax present in Searles Lake have been variously estimated. The earlier estimates, based on an exposed surface area of 11 square miles, a depth of 60 feet, and a brine content of 25 per cent of the cubical dimensions, arrived at the conservative figure of 4,000,000 tons actual potash. As the deposit came to be better understood, it was realized that the brine extended to a greater depth, covered a larger subterranean area, and occupied a higher percentage of the cubical contents. It is now known that brine can be pumped from an area of 13,000 acres, that it extends to a depth of 70 feet, and that it occu-

pies about 60 per cent of this space. On this basis the deposit contains about 20,000,000 tons actual potash.

The latter estimate is strengthened by the consideration of the potash present in the crystalline mass and recoverable through natural agencies, such as the seepage of rain water through the crystalline body and the consequent leaching out of the potash therefrom.

From this estimate and the above analysis, it is possible to show that the borax content is approximately 25,000,000 tons sodium tetraborate.

OPERATIONS AT SEARLES LAKE

The large-scale recovery of potash from Searles Lake brine was inaugurated in 1911 when the American Trona Corporation erected its first plant at Trona. The original plant was later demolished and a second constructed on an adjoining site and subsequently greatly enlarged and modified to form the present elaborate plant.

The method adopted and successfully applied to the production of potash consists essentially in the evaporation of the brine as received from the lake in multiple-effect evaporators, with the elimination of the surplus sodium chloride and sulphate to the point where the solution is practically saturated with potassium chloride and sodium borate, followed by cooling for the separate crystallization of these. This is an exceedingly simple procedure, when the extreme complexity of the brine is recalled.

In the crystallization of such salts a long list of possible compounds may be produced, and it is essential that a thorough understanding be had of these and the conditions under which they are formed. To maintain the conditions under which the various salts are separated from one another in a high state of purity is an exceedingly difficult matter—until the technique is understood. Before this end could be attained, a great deal of research was necessary. The problem has been complex. The results obtained to date,

based on elaborate, fundamental researches in the physical chemistry of this brine, represent a high degree of success.

While the initial exploitation of Searles Lake antedated the inauguration of the Great War, the incidence of the war, with its concurrent demand for potash of any sort at any price, caused a marked activity in efforts to increase the output of potash from that source. Additional plants were constructed, notably that of the Boro-Solvay Company,



Potash Plant, American Trona Corporation at Searles Lake, California.

which continued in operation during the war period. A third enterprise was started which adopted methods based on solar evaporation. Since the close of the War the latter two plants have been shut down and dismantled, leaving in operation only that of the American Trona Corporation.

From the fact that the plants more recently constructed at Searles Lake were dismantled on the ending of the War, the inference may be drawn that their operations were not of such a favorable character as to warrant their continuance under normal conditions. The reasons for such a result

would not be hard to find. The period of acute potash shortage was not long enough to admit of the elaboration of manufacture where the problems to be solved were so complex. There was not time enough in which to place these enterprises on a successful economic basis. A large tonnage of potash was produced, but at a cost which would not admit of peace-time profits. The American Trona Corporation, the company that had devoted the most time and effort to fundamental chemical research, was the one that was enabled to continue in operation. The continued development of its processes, cheapening its manufacturing costs and improving the quality of its products, has enabled it to survive successfully the post-war period characterized by exceedingly severe economic conditions.

PRODUCT

The quality of the potash produced at Searles Lake has steadily and markedly improved. Potassium chloride of 85 per cent purity followed that of 80 per cent and was followed in turn by products of 90 and 95 per cent purity. For a considerable period the output of the plant has averaged something over 61 per cent actual potash, corresponding to a muriate content of 96 to 98.5 per cent. This fact establishes this product as the highest grade of potash ever freely offered on the fertilizer market.

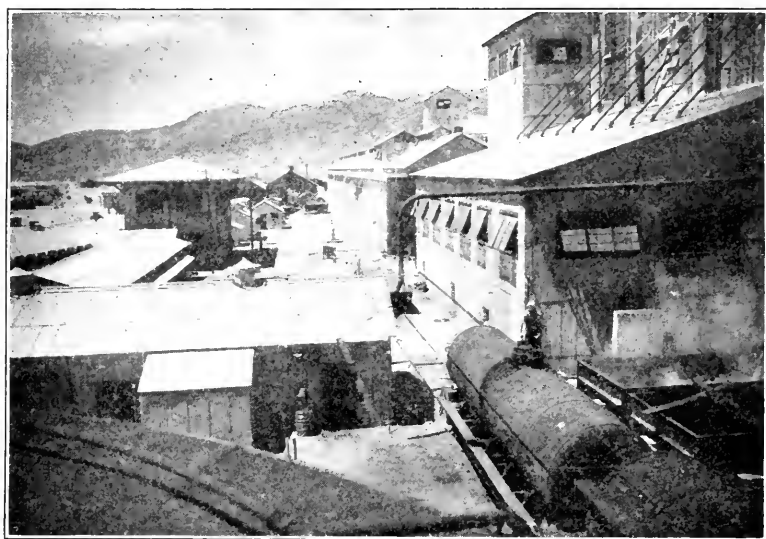
TABLE XXIII
ANALYSIS OF TRONA MURIATE
(Former product)

| | Per Cent |
|--|----------|
| Potassium chloride (KCl)..... | 88.35 |
| Sodium biborate ($\text{Na}_2\text{B}_4\text{O}_7$)..... | 0.34 |
| Sodium carbonate (Na_2CO_3)..... | 1.33 |
| Sodium chloride (NaCl)..... | 3.40 |
| Sodium sulphate (Na_2SO_4)..... | 2.76 |
| Water..... | 3.79 |

The present plant of the American Trona Corporation, in operation at Searles Lake, is the largest single potash

producer that has resulted from American efforts to establish a domestic potash industry. It is at present producing at the rate of considerably over 100 tons of potassium chloride per day.

The present process, which makes possible the complete separation of potassium chloride from borax with a recovery of both in a high state of purity, is based on the principle of rapid cooling of a brine approximately saturated with



Potash Plant, American Trona Corporation.

both. It represents a very great advance in the technique of potash recovery over the process originally employed, and so far as the complete separation of these two products is concerned, appears to be the ideal solution of that problem.

The utilization of the sodium sulphate and carbonate, yielded as by-products of potash and borax manufacture, still remains to be developed to its full possibilities. These products may be able to make further contributions to the economic strength of this valuable enterprise.

SOLAR EVAPORATION

The ideal process of recovering potash and borax from Searles Lake brine, it would appear, should be based on solar evaporation instead of the present expensive artificial evaporation with the use of fuel. As the lake is situated in the desert, ideal conditions are afforded for natural evaporation. An exceedingly low humidity, high winds and, particularly in the summer, very high temperatures would make it appear unnecessary to use fuel for evaporation. Extensive investigations of solar evaporation have failed to result to date in the adoption of a successful commercial operation. Processes involving the principle of solar evaporation have been proposed by Dolbear and others and are now undergoing commercial demonstration, but have not yet been applied on the manufacturing scale. They offer great promise, but it remains to be seen what the results of their large-scale application will be. The opinion may be expressed that the problem of an ideal process will not be solved until solar evaporation has been made to supplant the artificial. The large expense involved in the purchase and transportation of fuel oil and the operation and maintenance of elaborate evaporating systems make it imperative that the natural conditions favoring solar evaporation be utilized to the fullest extent.

Herein lies a most promising field of chemical investigation. Exhaustive researches have been made covering the equilibria existing between the various constituents of this brine over a considerable range of temperatures. It is thoroughly well known how these equilibria change with changing temperatures and concentrations. Conditions brought about by artificial evaporation are thoroughly well understood. Likewise, many of the conditions induced by solar evaporation have been established. The difficulty has been the control of the latter conditions. This field of research has by no means been neglected. However, a satisfactory commercial process based on solar evaporation is

yet to be fully demonstrated. Herein, it would appear, lies the ultimate solution of the problem of the most advantageous recovery of values from this great natural source of potash and borax.

THE DOLBEAR PROCESS

With a favorable foundation on the principles of solar evaporation and selective extraction, the Dolbear process for the separation of the constituents of potash-borax brines of the Searles Lake type has attracted much attention. As contrasted with the Trona process of selective crystallization, it depends on selective extraction. Thus the total saline content of the brine, a mixture of potassium chloride and sodium borate, carbonate, sulphate, and chloride, representing the total solids yielded by the solar evaporation of the brine, are leached with hot brine of a composition and concentration, in the constituents other than potash and borax, such that only these two salts are dissolved. Thus these salts are extracted from the mixture and are subsequently precipitated by cooling. Advantage is taken of the differential in crystallization rates, to effect the separation of the two in such a state of purity that marketable products are obtainable with further simple manipulation. The residual mixture of sodium carbonate, sulphate, and chloride, freed from potash and borax, may then be processed for their separation.¹

The Dolbear process has been the subject of pilot-plant-scale experimentation with encouraging results, and offers the distinct promise of becoming of industrial importance.

¹ For an estimate of the Dolbear process, see the article, "Conquering Natural Brines for Commerce," by C. E. Bragg and W. P. Putnam, *Chem. Met. Eng.* **31**, No. 12, p. 468, Sept. 22, 1924.

POTASH FROM SILICATES AND OTHER MINERALS

POTASH FROM ALUNITE

OCCURRENCE OF ALUNITE

Of the American alunite deposits, found in the States of Nevada and Colorado and reported from various other states, it is the deposits of the State of Utah that have attracted most attention and are best known. Since their description by Butler and Gale in 1912,¹ they and the mineral obtained from them have been under frequent investigation. During the war years they were actively exploited by several companies, one of which, the Mineral Products Corporation, later purchased and operated by the Armour Fertilizer Co., carried the development of process and plant farther than did the other companies and produced important quantities of potassium sulphate for the fertilizer trade.

The Utah deposits are found in the Tushar Mountains of southern Utah, in the Marysvale district. The mineral occurs in lenses, dikes, or massive veins of irregular formation and of varying purity.

COMPOSITION OF ALUNITE

The composition of pure alunite may be expressed by the formula, $K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$; it may be described as a hydrated basic sulphate of potassium and aluminium. Its theoretical composition is therefore as follows: 11.4 per cent potassium oxide, 37 per cent alumina, 38.6 per cent sulphur trioxide, and 13 per cent water of composition. It generally carries varying and considerable quantities of impurities, principally silica. The following analyses illustrate the composition of the high-grade (samples No. 1 and No. 2)² and medium-grade material.

¹ "Alunite, A Newly Discovered Deposit Near Marysvale, Utah," U. S. G. S. Bul. 511, 1912.

² Quoted from Gale, "Potash in 1916," *loc. cit.*

TABLE XXIV

COMPOSITION OF ALUNITE FROM THE MARYSVALE REGION OF UTAH

| | No. 1 Per Cent | No. 2 Per Cent | No. 3 Per Cent |
|--|-------------------|-------------------|-------------------|
| Potash (K_2O) | 10.46 | 9.71 | 5.00 |
| Alumina (Al_2O_3) | 37.18 | 34.40 | 16.10 |
| Sodium oxide (Na_2O) | 0.33 | 0.56 | n. d. |
| Ferrie oxide (Fe_2O_3) | Trace | Trace | 4.51 |
| Sulphur trioxide (SO_3) | 38.34 | 36.54 | 16.80 |
| Silica (SiO_2) | 0.22 | 5.28 | 37.02 |
| Phosphoric acid (P_2O_5) | 0.58 | 0.50 | n. d. |
| Water (H_2O) | 12.90 | 13.08 | 2.00 |
| Loss on ignition at 650-700° C. . . | n. d. | n. d. | 17.00 |

These analyses serve to show the high degree of purity in which the material may be found, and, at the same time, the large inclusion of silica frequently encountered.

Chemical Properties.—In its natural state alunite is insoluble in water. It is easily decomposed by heat, whereupon at a temperature of about 750° C. the water and a part of the oxides of sulphur are evolved and the potash and alumina are broken apart, the former becoming potassium sulphate, soluble, and the latter aluminium oxide, insoluble in water. Thus the two are separated by the simple process of roasting and leaching with water, and these reactions have been made the basis of the processes heretofore employed in commercial operations. Were the material of a uniformly high grade its manipulation would be a relatively simple matter, and would result in the convenient production of three products, potassium sulphate, alumina, and oxides of sulphur, all of commercial value. Unfortunately the insoluble residue, the alumina, must be purified to rid it of silica and other natural impurities, and the oxides of sulphur evolved in the kiln gases so far have had no commercial use in the regions where produced.

It must be remembered that heretofore the work on the chemistry of alunite has been conducted principally from

the point of view of potash production. It is suggested that the successful solution of the problem of its commercial utilization will not be reached until emphasis is placed on the alumina as a raw material for aluminium manufacture, rather than on the potash.

QUANTITIES OF ALUNITE

The lack of uniformity of the alunite found in deposits under exploitation adds an element of uncertainty to the quantities of workable material contained and amounts of potash potentially available. Some idea is conveyed, however, by the surveys made of one group of claims, namely, the "Close-In" properties, where it is circumstantially estimated, for valuation purposes, that there are 3,000,000 tons of proved ore, 5,000,000 additional tons of probable ore, and a still further quantity of 5,000,000 tons of "prospective" ore, or a total of partly proved and partly estimated ore of 13,000,000 tons.

The composition of this body is represented by sample No. 3 in the foregoing table of analyses, in accordance with which the quantity of potash here represented is from 150,000 to 650,000 tons actual potash.

The alunite at present completely blocked out in the Armour properties is given at 500,000 tons, with an additional estimated quantity of 500,000 tons in place above the lower tunnel, but not entirely measured in three dimensions. The depth of the deposit below this level has not been determined, but there is evidence that it goes to great depth and that the total tonnage of ore here present is probably several times the foregoing conservative estimates.

While from the nature of the case these figures are based partly on estimates, they will serve to show the presence in these deposits of raw material sufficient to constitute the basis of an industry which will be capable of producing substantial quantities of potash and alumina for a considerable period of time.

METHODS AND COSTS OF PROCESSING

Experimentation with the alunite obtained from the "Close-In" properties¹ showed that "extraction of 88 per cent of the potash was possible with alunite averaging between 5 and 8 per cent, crushed to one-half inch and roasted for one hour at 800° C., or for half an hour at 1000° C.; and that the loss by volatilization of potash during roasting is negligible in roasts up to a temperature of 1000° C.; that a maximum extraction of potash is obtainable with water heated to 98° C., in a leaching period of five minutes with agitation and with a pulp ratio of calcine to water of 1:3, provided the calcine will pass a 10-mesh sieve; that the calcine may be dropped hot into the leaching solution without detriment to the extraction of potash; and that the quantity of aluminium sulphate from a calcine of a properly conducted roast is small."

The process here contemplated accordingly provides for the following operations: (1) roasting and leaching of the alunite and the evaporation of the lixiviate for the crystallization of the potassium sulphate; (2) the treatment of the insoluble residue to separate the alumina from the silica, by mechanical concentration in water suspension on vibrating tables, after well-known metallurgical methods, this being preceded by "repulping" operations in which advantage is taken of the difference in hardness of the alumina proper and the silica which contaminates it, to effect the disintegration of the former without breaking up the latter, thus greatly facilitating the mechanical separation of the two; (3) the filtration of the purified alumina and its drying and marketing as a raw material for the manufacture of metallic aluminium, salts of aluminium, and abrasives; and (4) the recovery of the oxides of sulphur evolved with the kiln gases on roasting, for the manufacture of sulphuric acid to be

¹ As reported from the Utah State School of Mines and quoted from documents prepared by the Industrial Potash Corp., of Philadelphia.

applied to the preparation of double and triple superphosphate from phosphate rock for fertilizer purposes.

Potash.—Itemized estimates, from the above quoted source, of cost of processing for the extraction of potassium sulphate from this material, on a thousand-ton per day basis, including total costs from mining through roasting, leaching, and crystallizing and including repairs, overhead, taxes and insurance, arrive at a total of \$1.55 per ton of raw material. Since 11 tons of alunite of this grade are required to produce one ton of potassium sulphate of 98 per cent purity, the cost of the potash on this basis would be \$17.05 per ton. It will be observed that this method of computing costs of potash places the entire burden on that product and none on the by-products. The figures are based on ore carrying only 5 per cent potash and high in silica.

Alumina.—The composition of the insoluble residue after leaching for the recovery of potash is shown in the following table:

TABLE XXV

ALUMINA (INSOLUBLE RESIDUE) AFTER LEACHING

| | Per Cent |
|---|----------|
| Alumina (Al_2O_3)..... | 27.44 . |
| Silica (SiO_2)..... | 63.07 |
| Ferrie oxide (Fe_2O_3)..... | 7.62 |
| Calcium oxide (CaO)..... | 1.20 |
| Magnesium oxide (MgO)..... | 0.61 |
| Total..... | 99.94 |

“Experiments have conclusively proven that concentration of the residue can be accomplished down to one per cent silica by a simple table concentration using water.” The estimated cost of preparing alumina for market from concentration through filtering and drying (with waste heat) is \$1.50 per ton.

Sulphuric Acid.—Similarly, a cost of \$1.40 is derived for sulphuric acid of 60° Bé. The feasibility of preparing superphosphates from by-product sulphuric acid and Idaho

phosphates, for the market of the Middle West, has been demonstrated by certain smelters of the Rocky Mountain region.

These figures are presented to illustrate, in a general, qualitative manner, the nature of the estimates derivable in a study of the commercial aspects of the potash-from-alunite industry, and particularly to show the importance of developing by-products and the great contribution that they potentially make to the favorable appearance of the proposal.

In every such potash project where the successful production of potash depends on the simultaneous production of by-products, the extent to which the industry can be developed is measured by the market for that product whose market is most restricted. In the case of alunite, both potash and superphosphate will find a less restricted market than the alumina. However, this is far from restricted, since, for example, in 1920 the domestic consumption of bauxite was 521,000 tons, 69 per cent of which was applied to the manufacture of aluminium; 10 per cent, salts of alumina for chemical use; 19 per cent, abrasives; and 2 per cent, refractories.

PROSPECTS

There is apparently no reason why a potash industry may not be established on the basis of alunite as the raw material. As is the case with every other source of potash so far studied in this country, alunite cannot be expected to do more than contribute its quota to the total quantity of potash required. It alone will not, nor will any other source at present known, constitute a solution of the problem of American potash. At the same time, it is a very promising raw material and, with the efficient production of by-products, should be a profitable and substantial source of potash of a form highly acceptable in American agriculture.

Alunite is relatively a newly discovered raw material. Despite the excellent order of talent applied to its study, it

still presents some unsolved problems. While the processes to which it is subjected for the recovery of its values are relatively simple, they involve difficulties that are not easily avoidable. The roasting of the ore, for example, if carried too far yields on leaching an alkaline solution, and if not carried far enough, yields an acid solution which leads to the precipitation of hydrated alumina and to consequent interference with easy evaporation and filtering. Uniformly perfect roasting in a direct-fired rotary kiln is not automatically accomplished. Also, where pulverized coal is used as fuel, the incandescent ash of the coal combines with some of the potash of the charge to form insoluble silicates, a difficulty avoidable by the use of oil, or the substitution of other types of roasting furnaces.

The decrepitation of the charge undergoing roasting, together with the fines already present, creates a great deal of dust which is blown out of the stacks and lost if some adequate provision is not made for its recovery. As the dust is made up of raw, partially calcined, and completely calcined alunite, its return to the system introduces complications. It is therefore desirable that dust formation be suppressed in so far as it is possible to do so.

Opportunities are offered for the development of valuable derivatives of alumina, the various salts and alums, aluminium nitride by nitrogen-fixation methods, and metallic aluminium by new methods of reduction. The present stage of the art of utilizing alunite need not therefore be taken as the final one. Alunite still represents a fruitful subject for research and, while the data at hand are sufficient to warrant the exploitation of that raw material, they do not represent the limiting possibilities which it offers for useful and profitable application.

POTASH FROM LEUCITE

The conspicuous American occurrence of the potash mineral, leucite, is in Wyoming, where it is found as a con-

stituent of wyomingite and other volcanic rocks making up the bulk of the Leucite Hills of Sweetwater County.¹ The rock-masses forming the Leucite Hills rise abruptly from the table land of the region to form mesa-like structures exposing extensive vertical faces, 50 to 150 feet high. They are accordingly easily accessible for large-scale quarrying operations.

While in the lavas of the Mt. Vesuvius region of Italy, leucite is found as large crystals, in wyomingite the particles are microscopic, 0.01 to 0.05 mm. in diameter. It is only one of several minerals which contribute to the potash content of these rock.

COMPOSITION OF LEUCITE ROCKS

The minerals entering into the composition of wyomingite, typical of the leucite rocks, are shown in the following table.² Among these, leucite, phlogopite, sanidine, and a glassy siliceous base contain most of the potash. Any efficient method of recovery must accordingly be applicable to these four. The rock which they constitute is generally quite cellular in structure, the porosity being particularly pronounced in wyomingite.

TABLE XXVI

APPROXIMATE MINERAL COMPOSITION OF ROCKS FROM BOARS TUSK

| | Per Cent |
|-------------------------|----------|
| Uncombined silica..... | 18.7 |
| Leucite..... | 26.1 |
| Noselite..... | 8.7 |
| Diopside..... | 18.8 |
| Phlogopite..... | 19.9 |
| Accessory minerals..... | 7.8 |
| Total..... | 100.0 |

¹ Cf. Schultz and Cross, "Potash-bearing Rocks of the Leucite Hills," Bul. 512, U. S. G. S.

² Schultz and Cross, *loc. cit.*

The composition of the minerals here involved is shown, as follows:

TABLE XXVII

COMPOSITION OF THE MINERALS OF THE LEUCITE-BEARING ROCKS *

| | Leucite | Sanidine | Diopside | Phlogopite |
|----------------------------------|---------|----------|----------|------------|
| Potash (K_2O)..... | 21.5 | 16.9 | .42 | 10.70 |
| Alumina (Al_2O_3)..... | 23.5 | 18.4 | ..... | 12.8 |
| Silica (SiO_2)..... | 55.0 | 64.7 | 50.86 | 42.56 |
| Titanic oxide (TiO_2)..... | ..... | ..... | 3.03 | 2.09 |
| Chromic oxide (Cr_2O_3)..... | ..... | ..... | ..... | .73 |
| Ferrie oxide (Fe_2O_3)..... | ..... | ..... | 1.19 | 2.73 |
| Ferrous oxide (FeO)..... | ..... | ..... | 1.82 | .90 |
| Magnesia (MgO)..... | ..... | ..... | 17.42 | 22.40 |
| Baryta (BaO)..... | ..... | ..... | ..... | 1.00 |
| Lime (CaO)..... | ..... | ..... | 23.23 | .20 |
| Soda (Na_2O)..... | ..... | ..... | .76 | .44 |
| Water (H_2O)..... | ..... | ..... | .31 | 2.35 |
| Fluorine (F)..... | ..... | ..... | ..... | 2.46 |
| Other substances..... | ..... | ..... | .03 | 06 |
| | 100.0 | 100.0 | 99.16 | 100.80 |
| Less O for F..... | ..... | ..... | ..... | 1.03 |
| | | | | 99.77 |

* From Schultz and Cross, *loc. cit.*

The composition of the rock as a whole is indicated by the approximate analysis presented in the following table:

TABLE XXVIII

ANALYSIS OF LEUCITIC ROCKS OF WYOMING

| Approximations | Per Cent |
|---------------------------------|----------|
| Potash (K_2O)..... | 11.0 |
| Alumina (Al_2O_3)..... | 11.0 |
| Silica (SiO_2)..... | 53.0 |
| Ferrie oxide (Fe_2O_3)..... | 3.0 |
| Magnesia (MgO)..... | 6.5 |
| Lime (CaO)..... | 4.5 |
| Soda (Na_2O)..... | 1.5 |

The various analyses of these rocks show a potash content varying from 8 per cent to 12 per cent, with an average of 10.7 per cent, and an alumina content varying from 9 per cent to 13 per cent, with an average of 11.8 per cent. In twenty hills or deposits of these rocks in this neighborhood there is a computed quantity of approximately 2 billion tons of ore, containing, on the basis of 10 per cent of each, 200,000,000 tons of actual potash and an equal quantity of alumina.

METHODS OF EXTRACTION

The only large-scale attempt to extract potash from the leucite rocks of Wyoming was made during the war years when the Sterling process, as developed at Salt Lake City, was put into operation at Green River, Wyoming.

The Sterling Process.—This process, based on the volatilization principle, prescribed grinding, mixing with sodium chloride to aid in the liberation of the potash, and heating to fusion in rotary, direct-heat kilns, and the recovery of the resulting potash fume in bag filters. The process was continuous, the charge in powdered form entering at the cold end of the kiln and molten slag being discharged at the hot end. Only one product of value, potash, was recovered, the other constituents of the ore being discarded as slag. The period of high-priced potash was about to end when this process was applied on the large scale at the Green River plant. Accordingly it was not maintained in operation long enough to make possible the elimination of the difficulties there encountered. This prevented a successful outcome of the enterprise.

The potash was yielded here as the chloride, of rather low purity, due to incomplete separation of the potash fume from the dust carried along with it.

In any attempt to pass from a powder to a completely fused and flowing stage by a continuous and automatic method, as in a rotary kiln, a stage of incipient fusion is

encountered during which neither the free-flowing characteristics of a powder nor the more sluggish movement of a slag can be relied upon to keep the charge moving by gravity flow. Such a condition may be called the "dough" stage, and it was this condition which, encountered in the rotary kilns employed in the Sterling plant, represented one of the difficulties there to be overcome.

It is not certain that a satisfactory volatilization of the potash cannot be obtained at lower temperatures or from mixtures of higher melting points. If this can be done, it will be possible to maintain conditions more nearly similar to those observed in cement kilns, whereby the charge, even though heated to the incipient fusion or clinkering stage, does not lose its free-flowing characteristics.

However, in the absence of definite estimates of costs, it appears quite improbable that the potash of the leucite rocks can be extracted by the volatilization or other process and be shipped thence to the eastern market in successful competition with the European article, unless other products are obtained simultaneously to carry much of the cost of processing. High freight rates from Wyoming represent a cost not easily to be countered by the ingenuity of the inventor as long as he has to rely on only one product to yield proceeds.

Solvent Methods.—The potash of leucite is, for the most part, easily extracted with acids of various sorts and concentrations. This principle, it has been seen, is made the basis of the process employed in Italy, where the leucitic rocks of the Rocca Manfina region are treated for the manufacture of potash.

It has been shown in the laboratories of the Bureau of Soils¹ that leucite is easily decomposed by sulphurous acid, that acid being considered because it is the one produced in large quantities as a by-product of the smelting industry of the Rocky Mountain region, and still for the most part

¹ "The Solubility of Leucite in Sulphurous Acid," J. Schroeder, *J. Ind. Eng. Chem.* 8, 779 (1916).

is a waste product whose disposal in some instances represents a serious problem. These experiments showed that 75 per cent of the potash of Italian leucite could be extracted by leaching with an approximately saturated solution of sulphurous acid, indicating a possible use of smelter fumes containing sulphur dioxide as the basis of a process for extracting potash from wyomingite.

In studying methods for the decomposition of this material, sulphuric acid as a reagent should receive particular attention as it is quite possible that any demand for that commodity in the Rocky Mountain region can be met through the conservation of the oxides of sulphur now lost in smelter fumes. This conservation is now realized in important instances and may easily be extended.

Studies should be made of the magnetic properties of these minerals with a view to their concentration, preferably at the quarry, to reduce transportation and other charges. The natural, accentuated porosity of wyomingite, in particular, will be an aid in crushing and grinding and in any attempts at extraction by percolation.

Because of the ease with which it may be decomposed, leucite lends itself readily to the various other methods proposed for the extraction of potash and alumina from silicates.

In the leucite rocks of Wyoming it is evident that there is an enormous supply of potash and alumina, occurring together in such a manner that the two may be recovered in one operation, mutually contributing to the success of any economical method of extraction. This is a fortunate combination in that the two together might be recovered profitably where either one alone possibly could not be. Their geographical isolation with respect to agricultural and industrial regions will militate against their early exploitation, but ultimately they will be enabled to contribute important quantities of potash and alumina, respectively, for the American agricultural and metallurgical industries.

POTASH FROM FELDSPAR

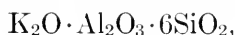
Feldspar is generally recognized as the potash-bearing mineral of greatest tonnage and widest distribution. Accordingly, it is the potash mineral that has received the greatest amount of study, and for its processing the greatest number of methods have been devised. To date, none of these has been placed under successful exploitation. They have served rather to retard utilization as they have created the impression that the extraction of potash from this ore is impracticable.

In the past the problem has been attacked from the point of view of potash production. The potash has been required to carry all the costs of extraction, which is not feasible if that product is to compete with the imported commodity. Present investigations and present processes now under consideration are radically different in that emphasis is placed on other products, particularly alumina, and potash is treated as a by-product and is expected to contribute only so much to the proceeds as its sales price will allow. This line of attack has at once brought these undertakings much nearer their objective.

Accordingly, instead of being relegated to the class of minerals no longer to be considered a potential source of potash, feldspar now promises to assume importance as a raw material for that manufacture.

COMPOSITION AND OCCURRENCE

Feldspar is a silicate of potash and alumina,



containing theoretically 17 per cent potash, 18 per cent alumina, and 65 per cent silica; but generally only 10 to 12 per cent potash is found. Frequently soda replaces the potash to an extent which further reduces that percentage. The mineral is hard and refractory, and for decomposition and the liberation of its potash by most proposed methods

requires a heat treatment at high temperatures after thorough grinding and intermixing with some base to replace the potash in its silicate combination.

Workable deposits of high-grade feldspar are found distributed throughout the industrial East and in regions readily accessible to the agricultural South. It occurs in dikes, lenses, or other massive formations, thus admitting of mining by the less expensive methods. Deposits are accessible to sources of supply of auxiliary materials and reagents, and within easy reach of regions of large potash consumption. There is no reliable estimate of the total quantities available, but they may be described as immense and practically inexhaustible.

METHODS OF PROCESSING

No attempt will be made here to review the many processes described and patented for the extraction of potash from feldspar.¹ No method, it is suggested, which does not by a simple process produce both potash and alumina, in marketable form and in large tonnage, need be considered.

The Doremus Process.—Of especial interest and importance in this connection, and illustrative of the sort of methods which must be emphasized if the profitable recovery of potash from such silicates is to be realized, is the novel process invented by the late Dr. Chas. A. Doremus, whereby feldspar is decomposed by hydrofluoric acid in aqueous solution. This method of potash recovery is highly significant in that it has been designed primarily for the recovery of alumina from bauxite, potassium-aluminium silicates, and other natural aluminium compounds. By virtue of its applicability to potassium-aluminium silicates, it becomes a process for potash recovery with the particular advantage that it provides for a major product, alumina, with potash as the by-product. While it is deemed commercially feasible for the manufacture of alumina alone, as a

¹ For such a list, *cf.* Chem. & Met. Eng., 1918, p. 33.

substitute for the present generally employed Bayer process of alumina manufacture, its economic possibilities are greatly strengthened by the proposed simultaneous production of potash.

The Doremus process depends on the use of hydrofluoric acid as the agent for the dissolution of the aluminium ore. Feldspar, Georgia shales, and other potassium-aluminium silicates are soluble in dilute aqueous solutions of this acid.

As applied to feldspar, the process consists essentially in treating the finely ground material with 20 per cent hydrofluoric acid in the proportion of 20 parts of the former to 129 parts of the latter by weight, or as calculated on the basis of analysis of the mineral. A prescribed, initial temperature of 50° C. is raised by the exothermal reaction. The alumina goes into solution as the fluoride, while the potash and silica recombine to form an insoluble precipitate of potassium silico-fluoride which is separated by decantation or filtration. Any excess of silica, over that required to combine with the potash as the silico-fluoride, is precipitated as hydrated silicon dioxide, provided there are enough bases present to combine with both the hydrofluoric and hydrofluosilicic acid. From the highly concentrated solution of aluminium fluoride that salt is crystallized by an ingenious procedure and is then heated in the presence of steam to form hydrated aluminium oxide with the regeneration of hydrofluoric acid.

The potassium silico-fluoride may be heated with sulphuric acid with the volatilization of hydrofluosilicic acid and the formation of potassium sulphate; or it may be heated with calcium sulphate in molecular proportions, whereupon silicon tetrafluoride is volatilized, and an interchange of acids takes place between the potassium and the calcium to form a friable mixture of potassium sulphate and calcium fluoride. These are separated by lixiviation, which yields a solution from which potassium sulphate is crystallized as a high-grade product.

From all the compounds of fluorine here produced, hydrofluoric acid is easily regenerated. That reagent may therefore be used cyclically with only moderate losses to be met through fresh additions.

This process, in an experimental plant at Mamaroneck, N. Y., yielded alumina of a purity of 98-99 per cent, conforming with the requirements of the trade, and a recovery of hydrofluoric acid of 92 per cent. In this demonstration, bauxitic clay, containing 45 per cent alumina and 35 per cent silica, was employed. Potash recovery was therefore not involved. On the data here established, production costs and plans for a large production plant were based. The project accordingly has had thorough study and has been given an impressive demonstration. Under the pre-war conditions obtaining at the time of the demonstration, the production cost per ton of alumina by the Doremus process was estimated at \$21.04, as contrasted with a cost of \$31.20, by the Bayer process. These figures are presented here to convey some idea of the enhanced economies to be expected when a potassium-aluminium silicate is substituted, yielding potash as a side-product with but slight increase in manufacturing details and costs.

Designed by a chemist of the eminence of Dr. Doremus and based for its claims on large-scale experimentation, this process constitutes a forceful argument for the strengthening of one's faith in purely chemical solution methods of treating the potassium aluminium silicates for the concurrent production of potash and alumina.

The McClenahan Process.—The decomposition of potassium aluminium silicates by ammonium bi-fluoride in water solution is made the basis of the McClenahan Process.¹

In this process finely ground feldspar is treated with an excess of the reagent, whereupon thorough decomposition takes place with the formation of a solution of ammonium silico-fluoride and the insoluble compounds, potassium silico-fluoride and ammonium aluminofluoride. The solids

¹ U. S. P., Nos. 1,426,890 and 1,426,891.

are settled and, after the decantation of the supernatant solution and washing, are heated in the presence of steam at 650° F., whereupon the last of the silica is driven off as volatile ammonium silico-fluoride and the alumina becomes partly the potassium alumino-fluoride and partly the hydrate. On treating this mixture with lime and caustic alkali, the potash and alumina go into solution, leaving behind a residue of calcium fluoride and the insoluble impurities derived from the original ore. From the calcium fluoride herein contained, hydrofluoric acid is recovered by a sulphuric acid treatment. The caustic solution is treated with carbon dioxide to precipitate the alumina and to convert the potash into carbonate.

The original solution, with which has been combined all of the silica as ammonium silico-fluoride, is treated with ammonia for the precipitation of silica. Finally, the filtrate is evaporated to dryness with the volatilization of ammonia and the regeneration of the original reagent, ammonium bi-fluoride.

The caustic alkali and the ammonia are used cyclically. The products obtained are alumina, as the "heavy" hydrate, free from iron, silica, and other impurities; potash, as carbonate and of a purity determined by the amount of sodium present in the feldspar; and silica, finely divided, amorphous, and of high purity. The main cost involved in the process, assuming an efficient cyclic recovery of ammonia and hydrofluoric acid, apparently is represented by the evaporation of 2.5 tons of water per ton of feldspar treated, a quantity which seemingly it should be possible to reduce. A point of interest and of potential importance in favor of the McClenahan process is that the potash produced therein is in the form of carbonate, a form ideally adapted to the preparation of potash salts for use in the modern concentrated fertilizers. In such a form it can be used to neutralize phosphoric acid with the evolution of a very volatile and non-corrosive acid, making possible the easy manufacture of potassium phosphate or potassium-ammonium phosphate,

in marked contrast, in that particular, to potassium chloride or sulphate.

This form of potash would also be very useful in the absorption of nitric acid gases in the manufacture of synthetic nitrates from atmospheric nitrogen, and in that industry would meet a long-felt want. The product, potassium nitrate, would conform admirably with the modern program for concentrated fertilizers, where it would find ready acceptance.

POTASH FROM GREENSAND

The great, conspicuous, and easily accessible deposits of potash-bearing material known as the greensands, as they occur in New Jersey, Delaware, Maryland, and Virginia, have long been the object of research on the part of chemists and engineers seeking the utilization of American raw materials for the production of potash. However, on account of the relatively low potash content of this material, and for other reasons, these researches, from the point of view of the establishment of successful commercial operation, have so far been unsuccessful. Nevertheless, the solution of this problem might easily mean the solution of the entire American potash problem. It has enormous potentialities. In any comprehensive program of investigation of American potash resources, therefore, the greensands must have a conspicuous place. Any successful solution, as is the case with the other potash prospects, must be based on a consideration of by-products. So far as the development of any large and permanent potash industry is concerned, the New Jersey greensand beds are at present perhaps the most promising deposit of potash-bearing mineral. This statement is based on the consideration of the advantages which they possess, as for example:

1. Great size of deposits.
2. Uniformity of deposits.

3. Ease of mining.
4. Proximity to market.
5. Ease of extraction of potash.
6. Possibilities for by-products.

OCCURRENCE AND QUANTITIES

While greensand deposits have been found in other states, the New Jersey deposits are by far the most important in point of extent, situation, purity and ease of mining.

Mansfield,¹ in his excellent description of the New Jersey deposits, estimated that the greensand here available by open-pit mining methods alone would supply 257,000,000 short tons of actual potash. "At the rate of importation for the five years preceding the World War, including 1914, this quantity could supply the United States for nearly one thousand years." If consideration were given to the additional quantities obtainable by underground mining, these figures would be greatly increased. Washington² has estimated the content of the New Jersey beds at 2,034,000,000 metric tons (2,242,100,000 short tons) and the dimensions at 160 kilometers in length (100 miles), with an average width of 16 kilometers (10 miles), and an average thickness of 6 meters (20 ft.). He states that, in point of quantity of potash contained, these deposits rank second only to the Italian leucites.

The New Jersey deposits are contiguous to the country's center of industrial activity. Railroads cross them at many points, and streams flowing across them into the Delaware river offer sources of ample water supply and opportunities for water transportation facilities.

As has been stated, potash sufficient to supply this country's needs for a thousand years is here available in raw material obtainable by open-pit methods, or within reach of the steam shovel.

¹ "Potash in the Greensands of New Jersey," U. S. G. S. Bull. **727**, 1922

² Chem. and Met. Eng., Vol. **18**, p. 17 (1918).

COMPOSITION AND PROPERTIES

Greensand has a marked advantage over most of the other potash-bearing minerals in that it occurs naturally in a finely divided condition, suitable for direct treatment without grinding. If grinding be necessary it can be accomplished with ease, as the material is soft and readily pulverized. Generally speaking, it is more readily attacked and decomposed by the various reagents than are the other potash-bearing silicates.

The uniformity of the deposits is such that, for the time being, it will not be necessary to consider preliminary purification. When purification becomes necessary the magnetic properties of the glauconite may afford a ready means. As applied to the run-of-mine material, magnetic concentration, it is stated, raises the potash content about 40 per cent.

Greensand, as the name indicates, is composed of unconsolidated mineral particles of a fairly uniform appearance, composition, and size, passing a 20-mesh sieve. Its green color is due to the presence of glauconite, a supposed mineralogical entity represented by the formula, $\text{KF}'''\text{Si}_2\text{O}_6 + \text{aq}$; but the particles themselves are not definitely crystalline, a fact from which arises considerable doubt as to their true constitution. The origin and nature of the material have received much study. These need not be discussed here, but in passing it may be remarked that among the physiochemical properties of the mineral the colloidal characteristics are outstanding.

Typical analyses of greensand are shown in the following table.¹

¹ Samples 1, 2, and 3 quoted from Mansfield, *loc. cit.* Sample 4 quoted from Shreve, "Action of Lime on Greensand," *J. Ind. Eng. Chem.* **13**, 693 (1921).

TABLE XXIX
ANALYSES OF GREENSAND

| Sample..... | No. 1 | No. 2 | No. 3 | No. 4 |
|-----------------------------------|--------|-------|--------|-------------------------|
| Potash (K_2O)..... | 6.60 | 6.68 | 7.88 | 7.4 |
| Silica (SiO_2)..... | 51.83 | 50.74 | 50.32 | 49.8 |
| Ferric oxide (Fe_2O_3)..... | 17.15 | 17.36 | 18.38 | 18.0 |
| Ferrous oxide (FeO)..... | 2.96 | 3.34 | 3.02 | .... |
| Alumina (Al_2O_3)..... | 6.23 | 1.93 | 7.53 | 9.8 |
| Lime (CaO)..... | 0.52 | 2.86 | 0.65 | 0.9 |
| Magnesia (MgO)..... | 3.66 | 3.76 | 3.82 | 7.7 |
| Sodium oxide (Na_2O)..... | 0.76 | 1.53 | 0.22 | 0.4 |
| Carbon dioxide (CO_2)..... | 0.36 | 0.88 | 0.15 | .... |
| Phosphoric acid (P_2O_5)..... | 0.31 | 1.79 | 0.34 | 0.25 |
| Water (H_2O)..... | 9.98 | 9.08 | 8.58 | Loss on ignition 5.6 |
| | 100.42 | 99.95 | 100.89 | 100.1 |

Blair¹ shows the average potash content of 20 specimens of greensand from various localities to be 4.57 per cent.

Commercial beds of greensand contain around 7 per cent of potash, 50 per cent of silica, 18 to 23 per cent of iron oxides (as Fe_2O_3), 7.5 to 10 per cent of alumina, 3 to 7.5 per cent of magnesia . . . The commercial beds carrying 5 to 7.5 per cent of potash, however, are chiefly within the State of New Jersey.²

By magnetic concentration, in the opinion of some, the potash content may be raised to 8 per cent. It is said to be entirely practicable to apply this method to the low-grade greensands and thereby raise their potash content to 6.5 to 7 per cent.

¹ "The Agricultural Values of Greensand Marl," N. J. Agr. Expt. Sta. Circ. 61, p. 12 (1916).

² Shreve, "Greensand as a Source of Fertilizer Potash," Am. Fertz., Dec. 31, 1921, p. 35.

THE PATENT LITERATURE ON GREENSAND

In the study of methods of obtaining potash from natural silicates, greensand has received its share of the attention of inventors. A long series of patents is to be found, covering processes, which may be classified into six groups as follows:

- (1) Processes employing autoclaving with subsequent recovery of potassium salts;
- (2) Processes employing roasting or heating without volatilization of potash, followed by leaching for the extraction of potash;
- (3) Processes in which potash is volatilized and subsequently recovered;
- (4) Processes using reagents in water solutions at low or moderate temperatures;
- (5) Processes for the direct production of fertilizer without the extraction of potash;
- (6) Miscellaneous processes.

This statement will serve to show the more popular lines of attack employed by those studying the extraction of potash from greensand.

COMMERCIAL UTILIZATION OF GREENSANDS

Various attempts have been made to utilize greensand commercially, but to date without any very great success. Desultory attempts at various times to develop the practice of direct application of greensand as fertilizer have not resulted in any general use of that material in that way. During the war years of potash famine, special efforts were made to develop a potash industry on the basis of this raw material. Several of these enterprises showed very decided promise of being about to result in successful commercial processes, but the end of the War and the attending decrease in price obtainable for potash, coupled with the uncertain-

ties of the years that followed, resulted in the suspension of most of this work.

No effort will be made here to give a detailed account in these operations other than to point out the essentials of the methods employed.

The Tschirner Process of the R. S. Ryan Co.—During the War years a process involving the mixing of greensand with “limesand” and salt, followed by heating, was exploited with encouraging results. “Limesand” is a natural material occurring in large tonnage near the greensand deposits in certain areas, sometimes constituting the overburden of the greensand beds. It contains about 48 per cent calcium carbonate. It is a convenient and inexpensive source of lime for such a process.

The three ingredients, in the proportion of 10 parts greensand, 12 parts limesand, and 3.5 parts salt, were mixed wet in a pug mill and heated in a rotary kiln to a temperature of about 800° C. The resulting clinker was leached to recover the potash, as potassium chloride, and that portion of the salt, about 66 per cent, which had not entered into insoluble combination. The two were then separated by crystallization methods, the recovered salt being returned to the process. The potash recovery in the small pilot plant operated was about 80 per cent efficient. Some potash was volatilized by the heat of the kiln; in a completely equipped plant this would be recoverable. It was estimated that in such a plant the process would be about 90 cent efficient.

At a cost of about 25 cents per ton for greensand and 50 cents per ton for limesand, a production cost of about \$40 per ton of 80 per cent muriate was derived for a plant of a daily capacity of 100 tons greensand. For a larger plant of 4700 tons daily capacity (10,000 tons total charge), with greensand at 10 cents and limesand at 15 cents per ton, a works cost of \$13 per ton of 80 per cent muriate was estimated.

These highly favorable estimates were derived without

any consideration of by-products. The potash carried all the costs of manufacture. It is not apparent that any by-product could be obtained by this process. However, with such a substantial foundation upon which to build, it would appear highly desirable that research be conducted along this line to determine whether other values cannot be recovered wherewith to construct a more economical process. Fair promise of favorable results is offered.

The Shreve Process as Applied by the Eastern Potash Corporation.—Noteworthy among the attempts to produce potash from greensand is that of the Eastern Potash Corporation under the technical direction of Mr. R. Norris Shreve, of New York. Experimentation was carried on at Jones Point, N. Y., for a number of years, particularly along lines suggested by the Charlton patents.¹

In outline, this process as now employed consists in heating a slurry made from 1 part of ground greensand, 1 part of lime, and 5 parts of water or weak washings in a digester for about 1 hour, at a temperature around 470° F., and under sufficient pressure to keep the water in the liquid phase. This will be somewhat over 500 pounds' pressure.

The chief reaction which takes place is that of the lime upon the greensand, which on the one hand liberates the potash in the form of a very pure caustic potash, and on the other hand produces a material high in lime, which possesses valuable cementitious and liming properties.²

The action of lime on greensand was studied with the following variables:

1. State of subdivision.
2. Temperature of digestion.
3. Ratio of water used.
4. The substitution of potassium hydroxide solutions for water.
5. Ratio of lime used.
6. Addition of various salts.

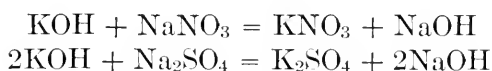
¹ J. Ind. Eng. Chem. **10**, 6 (1918).

² Shreve, "Action of Lime on Greensand," J. Ind. Eng. Chem., **13**, 693 (1921).

Among the many interesting observations made is the particularly valuable one that if sodium nitrate be added to the charge, the potash rendered soluble is increased from 61 per cent to 81 per cent, and, upon evaporating the solution resulting from the digestion, high-grade potassium nitrate is recovered, with the equivalent of caustic soda remaining in solution.

This fertilizer salt, potassium nitrate, is of especial value and interest in view of the emphasis placed, in modern practice, upon concentrated chemical fertilizers, as it carries two elements of plant food in a valuable and condensed form. In the mixing of chemical fertilizers with saline phosphate, such as mono-ammonium phosphate, as a base, it would be ideal for boosting either the nitrogen or the potash content, or both.

Caustic potash is the normal product of the action of lime on greensand. In this compound both the potash and the hydroxyl radical are valuable. However, there may be applications where the one is of value and the other is not. In such cases, the two may be divided and used separately if the procedure illustrated by the following equations be employed:



These considerations add materially to the value of the Shreve process.

The results of the Shreve researches are summarized in the statement that, to secure economic recovery of potash from greensand by the methods investigated, the following conditions should be observed:

1. Fine grinding, that is, 90 per cent to pass 200-mesh.
2. Digestion for 1 hour at 470–480° F.
3. A charge made up of greensand, quicklime, and water in the proportion of 1 : 0.9 : 5.

4. Addition of various salts for the purpose of:
 - (a) Accelerating the reaction (increasing the percentage recovery).
 - (b) Changing the potassium hydroxide to other potassium compounds, or a combination of (a) and (b).

These reactions were made the basis of the plans of the Eastern Potash Corporation which proposed the large-scale treatment of greensand (1000 tons per day) and for that purpose partly constructed a plant near New Brunswick, N. J. This company proposed to employ the extracted residue for the manufacture of building brick and, as it contained 40 per cent lime, as agricultural lime.

Their plans were designed for the manufacture of 500,000 brick per day (with sand-lime residue sufficient for 3,000,000 per day). At such a rate, potash equivalent to 75 tons of commercial potassium hydroxide (90 per cent KOH) per day would have been produced.¹

Obvious difficulties present themselves for solution before an enterprise of such magnitude can be put on a successful economic basis. These difficulties are well known to the management, and are being studied by competent persons. They need not be regarded as insurmountable, and if they are overcome a very important step toward the solution of America's potash problem will have been taken.²

The Bureau of Soils Process.—The efficacy of the siliceous adsorbents, such as fullers' earth, infusorial earth, and clays, among the natural products, and the silica gels, the so-called collodial clays, and bentonite, among the fabricated products, in the purification of oils in general and of petroleum products in particular, led to the thought that it should be possible to produce useful siliceous adsorbents from potash silicates as a by-product of potash manufacture,

¹ Ruckman, "Putting New Jersey's Potash Works on a Paying Basis," Rock Products, July 29, 1922.

² Cf. also "The Plant and Process of the Eastern Potash Corporation," by R. Norris Shreve, Concrete (Cement Mill Edition), March, 1922.

thus swelling the number of by-products to share with the potash the costs of manufacture.

Accordingly, the investigation of greensand as a source of potash in the Bureau of Soils was directed toward the development of a process for the large-scale production not only of potash and alumina, but especially of a siliceous product of such a character as would admit its use in the arts and industries as a decolorizing and purifying agent for use as a substitute for other siliceous adsorbents. The peculiar, natural colloidal nature of greensand made it appear readily adaptable to such a purpose. Furthermore, former processes had been directed toward the conservation and utilization of the smaller constituents of greensand and had ignored the silica, which constitutes 50 per cent of that raw material. The elaboration of the silica into a useful product, it was evident, would make it possible to utilize all of the constituents of the raw material and thus materially enhance the economies obtainable.

The Action of Acids on Greensand.—The potash of greensand, it has long been known, is readily soluble in the stronger inorganic acids. At the same time, in most acids, the other constituents, the iron and aluminium oxide, are also soluble. These constituents form compounds which in the past have not been sought, thus requiring the use of a large excess of the reagent over that needed to react with the potash, and carrying into solution with the potash other salts subsequently to be separated through purification methods more or less elaborate. Practical considerations impose the conditions that the acid chosen be a cheap one, that it be usable in a highly efficient manner, and that the salts produced concurrently yield values enough to sustain a considerable part of the cost of processing—a severe set of requirements.

Sulphuric acid was chosen as the reagent best meeting these requirements. While it had already been shown by various experimentalists in this field that greensand could be completely extracted with this acid, it remained to be

determined, first, whether it could be made to yield the silica in the form of an active adsorbent, and second, whether the potash, aluminium and iron sulphates could be fabricated into useful products.

The results obtained were affirmative. It was found that under properly controlled conditions the residue remaining after the extraction of the basic oxides, after washing, drying, and screening, was made up of non-crystalline silica in the form of granules representing the siliceous skeletons of the original greensand grains. Applied as a purifying and decolorizing agent, it showed marked adsorptive properties even in the crude state. In activity it proved quite equal to certain other well-known siliceous adsorbents in applications where tested and thus established for itself a fairly definite value.

The sulphates, yielded in highly concentrated solution, were found to be easily separable from one another in fair purity by fractional crystallization methods, the potassium and aluminium sulphates combining to separate first as alum, thus introducing no complication in the subsequent precipitation of the iron sulphates.

However, in order that the results here obtained might be made to serve most effectively in promoting the development of a potash industry based on greensand, it was essential that the processes yielding them be made to conform as closely as possible with lines of work being carried on by any industrial concerns laboring with a like objective, in the same field of endeavor. Most opportunely, announcement was made of the important results obtained by Mr. A. J. Moxham, President of the Electro Company, at Odessa, Del., in an experimental and demonstrational plant designed for the development of a process for the extraction of potash, aluminium and iron from this same raw material, greensand, and with the same reagent, sulphuric acid.¹

The lines of attack were so nearly parallel in the two

¹ "Purifying Iron Ore by Chemical Methods," by A. J. Moxham, The Iron Age, June 5, 1924.

researches that it required little modification in procedure to render the results obtained in the Bureau of Soils investigations entirely applicable in the Moxham process.

The Moxham Process.—The process employed by the Electro Company is an ingenious one, the result of elaborate investigations. It prescribes the digestion of greensand with chamber sulphuric acid and the manipulation of the resulting products after the following manner:

Greensand as obtained from the pits, without any preliminary treatment, is digested with hot, dilute sulphuric acid of a specific gravity of 1.30 to 1.40. The reaction starts at a temperature of 85–90° C., attained not by external heating but by the dilution of the acid with water and the heat of reaction of the acid on the greensand. With an excess of acid of about 25 per cent and with a moderate agitation of the reacting mass, the extraction is complete at the end of five to six hours.

The efficiency of the extraction is high, as shown by the following tabulation:

TABLE XXX

ILLUSTRATING EFFICIENCY OF ACID LEACH—ORE CHARGED 2200 LBS.

| Ingredient | Charged, Pounds | Recovered, Pounds | Efficiency of Leach |
|-----------------|--------------------|----------------------|------------------------|
| Iron oxide..... | 242 | 222.6 | 93% |
| Alumina..... | 133 | 130.2 | 98% |
| Potash..... | 107 | 107.0 | 100% |

Average temperature 99° C., Sp. g. of sol. obtained, 1.44.

The insoluble residue of granular siliceous material settles readily and is easily separated by gravity methods or by filtration. Any suspension remaining in the solution is separated by adsorbents, yielding a clear solution of the sulphates of potassium, aluminium and iron.

The choice is offered of several methods of precipitating and separating the sulphates, but the procedure preferred

is the simultaneous, one-operation precipitation of the bulk of the sulphates by the addition of sulphuric acid or by evaporation, the high concentration of the solution making this easily possible. The mother liquor containing the residual acid and sulphates is returned to the system.

The mixture of sulphates, made up principally of alum and iron sulphates, is roasted at a temperature of about 500°C . for the thermal decomposition of the iron sulphates into ferric oxide and the regeneration of sulphuric acid. Upon lixiviating, the roasted mass yields high-grade iron oxide and a concentrated solution of potassium and aluminium sulphates from which alum is crystallized. This salt in turn is roasted at a temperature of about 900°C . for its decomposition into potassium sulphate and alumina and the regeneration of a further quantity of sulphuric acid. On leaching the resulting mixture of calcined solids, potassium sulphate is dissolved, leaving the alumina. By a simple preliminary expedient the alum is rendered iron-free, so that the final product, alumina, is gotten in a high state of purity.

The insoluble residue from the original extraction of the greensand, consisting of the siliceous skeletons of the greensand grains and of quartz particles, an impurity present in the greensand, is first washed to recover the retained solution of sulphates, the wash-water being returned to the system. This is followed by further washing, drying, screening, to remove the quartz, grinding, and any further treatment required for the purification of the material and the development of its adsorptive and other properties. The trade name, "Glaucosil," has been assigned to this product.

The products yielded by the Moxham process, therefore, are iron oxide, ochers, alum, aluminium sulphate, alumina, potassium sulphate, Glaucosil, and fuming sulphuric acid, representing as finished products practically all of the constituents of the raw material from which they are manufactured.

The results so far obtained with this process appear to be

an entirely satisfactory solution of the problem of the profitable recovery of potash from this, the greatest of American potash resources. The process embraces a remarkable combination of favorable aspects: the extractive reagent employed is cheap; the procedure is simple, requiring little supervision, and susceptible of largely automatic, mechanical operation; the utilization of the raw material is practically complete; the various products yielded concurrently represent a well-balanced output, and all of them enter markets capable of absorbing a heavy tonnage, thus making possible large-scale operations; and the potash produced is amply supported economically by several other products, being thus placed in a remarkably strategic position for meeting the competition of the foreign commodity. As an added advantage, the potash is yielded as the sulphate, the form which, for the time being, receives a preferential price in the American market.

GENERAL CONSIDERATIONS

A survey of the many processes for the extraction of potash from greensand suggests a reason why none of the methods formerly proposed and put into operation has been successfully employed. This may be due to the fact that no one has as yet put into full commercial operation a process which developed a by-product capable of carrying any considerable portion of the manufacturing cost of the potash. Most of them involved high-temperature treatments followed by leaching and the evaporation of the resulting solutions for the crystallization of the potash. While affording a high-grade product, they failed to provide for the recovery of other values.

The Eastern Potash Corporation, as has been seen, based its war-time plans on the proposed utilization of the extracted residue for the manufacture of brick. This by-product of potash manufacture was of excellent character. The process provided for the production of the potash

in the form of caustic, itself yielding a high price as a chemical and easily convertible into forms more acceptable for fertilizer use, with the simultaneous production of another valuable by-product, caustic soda. This company's plans seemed to offer promise of success. Their process has a great deal to commend it, and it is to be hoped they will yet be able to put it into operation.

The slight unit value of most of the materials to be yielded from greensand as by-products results in the necessity of producing them on a large scale. The Moxham process has been designed particularly from that point of view. It owes its great potential value largely to that consideration. The ultimate goal here sought has been the simultaneous production of raw materials for three major industries—pure iron oxide for the steel industry, pure alumina for the aluminium industry, and potassium sulphate for the fertilizer industry.

The inventor has brought to bear on his present problem a wealth of experience gained in years of active participation in the development of the American iron and steel industry. These talents are now being applied to the development of an American potash industry. May the same degree of success attained in his former activities attend his present efforts!

The difficulties encountered to date, while serving to defeat past efforts to develop an acceptable commercial process, should not be permitted to prevent the thorough exploration of this field of industrial research, since the successful solution of the potash-from-greensand problem will mean the addition to our potash supplies of very large and important contributions of that essential material, and to a very considerable degree the solution of our potash problem.

POTASH FROM GEORGIA SHALES

The Georgia shales, known also as the Cartersville slates, extend from Cartersville, Ga., northeastward to a point where

contact is made with the Cartersville fault, a distance of 9 miles in a general northeastern and southwestern direction of strike. In this area, several miles in breadth, are workable beds of potash-bearing slate having a width of 1000 feet or more, and extending to a depth of thousands of feet.

The slates are soft and do not increase in hardness to any extent with depth. They can be mined with ease and at a low cost. The chemical character of the material does not vary after a depth of from 5 to 10 feet has been reached. The climate is equable, and favorable for open-cut mining throughout the year.

The strata carry an average value of 8 to 9 per cent of potash. The average of the analyses of several hundred samples is represented by the following tabulation:¹

TABLE XXXI
COMPOSITION OF GEORGIA SHALES

| | Per Cent |
|------------------------|----------|
| Potash (K_2O)..... | 8.79 |
| Silica..... | 57.10 |
| Alumina..... | 19.04 |
| Ferrie iron..... | 5.37 |
| Ferrous iron..... | 1.84 |
| Magnesium oxide..... | 1.92 |
| Calcium oxide..... | .01 |
| Titanium..... | .91 |
| Water plus..... | 3.52 |
| Water minus..... | .36 |
| Soda..... | .53 |

The conditions which affect the commercial development of the deposits, such as proximity to the fertilizer market and transportation facilities, relation of associated materials used in proposed chemical processes, and the situation of the deposit relative to fuel supply, water and the essential materials used in fertilizers, as sulphuric acid, nitric acid and the phosphates, are very favorable.

The slates of Georgia, being hydrous silicates, are decom-

¹ "The Potash-bearing Slates of Georgia," by T. Poole Maynard, Ph. D., Manufacturers' Record, Sept. 19, 1918, page 73.

posed much more readily than are the anhydrous silicates, e.g., orthoclase and feldspar. Potash can be volatilized from them more readily than from other silicates, and can be rendered soluble by heating with an amount of salt equal to two chemical equivalents of the potash, and of lime rock twice that of salt.

Favorable estimates of costs of potash from this source have been arrived at without consideration of by-products. To obtain by-products of potash extraction from such material, however, may prove difficult, since outside of the cement industry there are few instances where silicates of this nature are used in large quantities. The use of these slates in the manufacture of cement from the residue of potash extraction would therefore appear to be the more profitable plan. Volatilization of the potash, as a part of the usual process of cement manufacture, would seemingly be the simplest and least expensive procedure.

However, here again the application of strictly chemical methods commends itself. The commercial decomposition of Georgia shales by the Doremus process has already been made the subject of a prospectus with a favorable showing. As a potential source of potash and alumina, these deposits are of very considerable importance.

The same considerations apply here as in the case of other potash silicates containing alumina. Emphasis should be placed on that by-product. The Georgia shales contain a high percentage of alumina. It has already been found that under certain conditions they can be decomposed by sulphuric acid. This affords another promising line of attack and places the problem in a much more favorable aspect. This potential source of potash has been largely neglected. A great deal of work yet remains to be done; but it is by no means certain that this large deposit of potash mineral cannot be successfully exploited as a potash project.

POTASH FROM INDUSTRIAL WASTES: BY-PRODUCT POTASH—
ORGANIC

STEFFENS WASTE

The crystallization of sugar from the juices of sugar cane and sugar beets results in the accumulation of a residual solution, or mother liquor, in which are found the accumulated impurities or non-sugars naturally present therein. This residue, the well-known article, molasses, contains some sugar which cannot be removed in a pure enough state by ordinary crystallization methods. In the case of cane molasses, this sugar is utilized as a food, or as a constituent of cattle feed and as the basis of a large fermentation industry for the manufacture of alcohol. In the past, large quantities have been thrown away. In the beet-sugar industry, however, this sugar is commonly removed by the Steffens process wherein it is combined with lime to form calcium saccharate, a solid which is removed by filtration. The solution or filtrate thus obtained, now freed from sugar, is known as Steffens waste and contains only the non-sugars. In the past it has been discarded as valueless. Efforts to utilize it have been made, principally because of difficulties encountered in its disposal. It is dilute, very great in volume, and charged with odoriferous organic compounds, and its presence in streams or sewage systems constitutes a nuisance. Its disposal is a serious problem, forcing consideration of its utilization for the manufacture of by-products. Among these is potash. It is this necessity which gives this raw material economic importance as a source of potash for American agriculture.

COMPOSITION OF STEFFENS WASTE

As discharged from the filters, Steffens waste water is dilute, containing only 3 per cent solids. Its composition at this stage is shown in the following table.¹

TABLE XXXII

APPROXIMATE COMPOSITION OF TYPICAL WASTE WATER FROM STEFFENIZERS

| | Per Cent |
|------------------------|----------|
| Water..... | 97.0 |
| Total solids..... | 3.0 |
| Carbonate ash..... | 1.0 |
| Organic..... | 2.0 |
| Nitrogen..... | 0.16 |
| Potash (K_2O)..... | 0.35 |

The first step in its utilization is concentration, accomplished by evaporation. For this purpose the sugar evaporators are employed, the waste being stored during the campaign and evaporated at convenience. This results in a concentrated solution containing 50 to 55 per cent total solids. As the evaporators employed are multiple-effect, this is accomplished at a relatively slight expense. To obtain the composition of this product the above values for solids may be multiplied by the factor 17.

QUANTITIES

The potash taken from the soil by the American beet crop has been a matter of detailed study, so that fortunately we are able to estimate closely the potash potentialities of the beet-sugar industry. Variations from season to season and with soils and localities render more than an estimate unprofitable.

Mineral matter, or ash, carrying the potash content of the beet, is contained in a percentage of 0.89. Complete

¹ Zitkowski, "The Recovery of Potash from Beet-Sugar House Waste Liquors," J. Ind. Eng. Chem. **9**, 692 (1917).

analyses of the ash from beets from the States of California, Colorado, and Wisconsin are presented in the following table:

TABLE XXXIII

ANALYSIS OF ASH (MINERAL MATTER) FROM SUGAR BEETS FROM COLORADO, CALIFORNIA AND WISCONSIN. RESULTS IN PER CENT ON BASIS OF BEETS

| | Colorado, Per Cent | California,* Per Cent | Wisconsin,* Per Cent |
|---|-----------------------|--------------------------|-------------------------|
| Potash (K_2O)..... | 0.320 | 0.269 | 0.320 |
| Chlorine (Cl)..... | 0.102 | 0.065 | 0.040 |
| Sulphur trioxide (SO_3)..... | 0.028 | 0.034 | 0.024 |
| Phosphoric acid (P_2O_5)..... | 0.046 | 0.121 | 0.023 |
| Sodium oxide (Na_2O)..... | 0.097 | 0.106 | 0.089 |
| Lime (CaO)..... | 0.032 | 0.078 | 0.041 |
| Magnesia (MgO)..... | 0.058 | 0.051 | 0.047 |
| Iron and aluminium oxides ($Fe_2O_3 \cdot Al_2O_3$)..... | 0.042 | 0.014 | 0.027 |
| Silica (SiO_2)..... | 0.005 | 0.016 | 0.036 |

* Both the California and Wisconsin samples were several days in transit to the laboratory at which the analyses were made, and undoubtedly lost considerable moisture by evaporation, which consequently increased the percentage content of dry matter. Aside from that, the California sample was abnormally high in sugar content.

On the basis of a 6,000,000-ton crop of beets, the quantities of potash and nitrogen involved are respectively 18,000 tons and 13,000 tons.¹ Of this quantity of potash, 90 per cent is extracted with the sugar and becomes concentrated in the molasses. There being a production of molasses of 5.5 to 6 per cent, on the basis of the original weight of beets, the total yielded is about 360,000 tons, containing an average of 4.6 per cent actual potash, equivalent to about 16,000 tons. With the consumption of 40 per cent of this quantity in cattle feeds and 5 to 10 per cent in the distilling industry (from both of which the potash may be returned to the soil), a balance of about 45 per cent remains to be desugared by the Steffens process, and the waste therefrom constitutes the raw material for potash recovery. This contains a total

¹ Zitowski, *loc. cit.*

of about 7000 tons potash, a quantity which may be increased by (1) the growth of the industry and (2) the diversion of a larger proportion from the stock-feeding industry to Steffenizing plants.

METHODS OF DISPOSAL AND USE

In semi-arid regions where irrigation is practiced, the waste waters may be employed for irrigating the beet crop, thus restoring to the crop the potash, nitrogen, and phosphoric acid contained therein. This has much to commend it, though care must be exercised to prevent "souring the land."

In past attempts at utilization, particularly during the war years, the waste has been dried on a large scale to produce agricultural potash. The product yielded by the evaporators, containing about 55 per cent solids, has been reduced in drum driers to a solid containing 10 to 12 per cent potash and 5 per cent nitrogen; but as this product is very deliquescent and soon becomes wet again through the absorption of moisture, efforts have been made to convert it into an ash. The organic matter which it contains is sufficient to maintain combustion when once started, even with a content of 50 per cent water. This practice, fraught with technical difficulties, while yielding an ash containing 30 to 35 per cent potash, of a grade entirely acceptable for fertilizer use, results in the destruction of the organic matter and ammonia. This renders it impossible to obtain other by-products, puts all the charges on the potash, and makes the procedure economically unprofitable.

The composition of the potash thus obtained is shown in the table on p. 121.

The organic constituents of Steffens waste offer promise of useful by-products. It contains nitrogen in various organic combinations which by destructive distillation can be converted into agricultural ammonia. No method of utilization is to be regarded as satisfactory which does not, as the absolute minimum, recover this valuable ingredient.

This would more than double the value of the products without adding materially to the operating costs. Research will undoubtedly disclose other products which can effect a further division of cost of recovery with enhanced economies.

TABLE XXXIV

ANALYSES OF TWO SAMPLES OF POTASH OBTAINED BY THE INCINERATION OF CONCENTRATED STEFFENS WASTE

| | No. 1 Per Cent | No. 2 Per Cent |
|--------------------------------------|-------------------|-------------------|
| Potassium chloride (KCl)..... | 18.81 | 33.40 |
| Potassium sulphate (K_2SO_4).... | 8.09 | 2.79 |
| Potassium carbonate (K_2CO_3)... | 41.10 | 8.50 |
| Sodium carbonate (Na_2CO_3).... | 20.74 | 39.68 |
| Calcium carbonate ($CaCO_3$).... | | 1.14 |
| Ammonia (NH_3)..... | | 1.07 |
| Carbon (free)..... | 9.79 | 10.10 |
| Silica (SiO_2)..... | | 1.08 |
| Water (H_2O)..... | | 1.76 |

The Geldard Process.—It has been stated that in the evaporation of the dilute Steffens waste water to the concentrated product, the evaporating equipment of the sugar plant, consisting of multiple-effect evaporators, is employed. A concentration of 50 to 55 per cent solids is at present the limit, since at that point potash salts begin to crystallize and clog the apparatus. It has recently been shown by Geldard ¹ that, if provision be made for removing the salts as formed, the evaporation may be continued beyond this point to a concentration of 68.5 per cent total solids.

Sugar evaporators are not equipped for the separate removal of a crystalline product; but this deficiency, it is suggested, may be met by the installation of a small, auxiliary, vacuum crystallizer into which the saturated solution could be automatically transferred, and in which it could be cooled by evaporation in vacuum, after the manner of the

¹ W. J. Geldard, "Preliminary Results on the Utilization of Steffens Waste Water," presented before the Am. Chem. Soc., Ithaca Meeting, Sept., 1924.

process developed in the manufacture of potash salts from kelp at the Demonstrational Kelp Products Plant of the Bureau of Soils.¹ The potash salts, on account of their high heat coefficient of solubility, would crystallize out and could be removed. The mother liquor would then be returned to the evaporator, with fresh portions of solution to restore the original volume; and the process repeated until the solution became too concentrated in non-crystallizable ingredients to make further evaporation practicable. As applied to kelp potash brines, this process has been shown to be highly efficient and economical.

Geldard has shown that the salts obtained from Steffens waste by direct crystallization are high-grade potash salts consisting of chlorides and nitrates.

In these experiments he has shown that from 3420 pounds of Steffens waste, containing 47 per cent solids, 1420 pounds of water are evaporated to yield 2000 pounds of concentrate containing 68.5 per cent solids. During this operation 227 pounds of potash salts are deposited, which, on recrystallization, yield 199 pounds of salts of the following composition:

TABLE XXXV

ANALYSIS OF HIGH-GRADE POTASH SALTS OBTAINED BY GELDARD, BY
CRYSTALLIZATION FROM STEFFENS WASTE

| | Per Cent |
|----------------|----------|
| Potassium..... | 49.89 |
| Chlorine..... | 36.31 |
| Nitrate..... | 9.80 |
| Sulphate..... | 3.90 |
| Volatile..... | trace |
| <hr/> | |
| Total..... | 99.90 |

CONVENTIONAL COMBINATIONS

| | |
|-------------------------|-------|
| Potassium chloride..... | 66.90 |
| Potassium nitrate..... | 27.58 |
| Potassium sulphate..... | 3.92 |
| Volatile..... | 0.60 |

¹ Turrentine and Shoaff, "Potash from Kelp, VII—The Manufacture of Potash Salts," *J. Ind. Eng. Chem.*, **15**, 159 (1923).

An obvious advantage here obtained is the recovery of a considerable portion of the nitrogen present in the form of potassium nitrate.

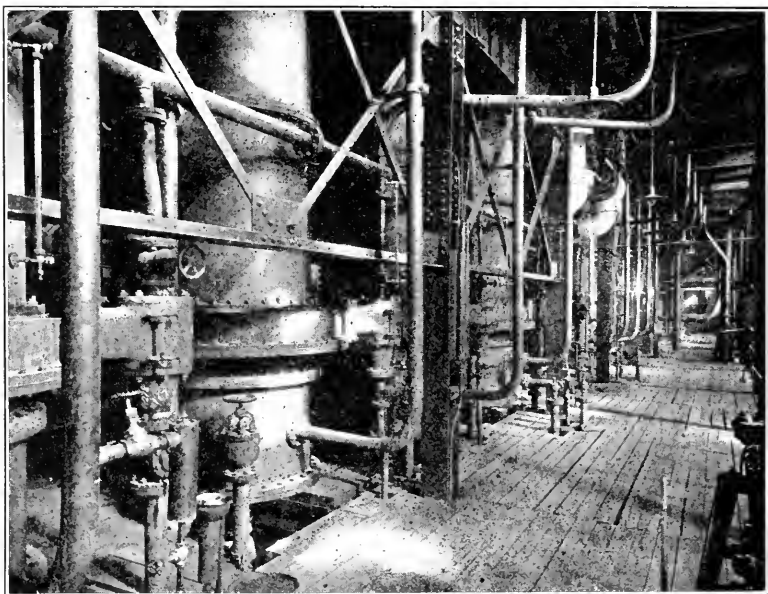
The Geldard method prescribes the carbonization or destructive distillation of the concentrated product, obtained as indicated. This yields volatiles of interesting properties, and a charcoal which may be activated to produce a decolorizing carbon of high efficiency. From the charcoal the residual potash and sodium salts are leached, and the resulting brine evaporated for their crystallization. From the quantity of concentrate given above, after carbonization, there was a yield of over 500 pounds of mixed salts with a content of about 38 per cent actual potash.

The Bureau of Soils Process.—At the Kelp Products Plant above mentioned, kelp was dried and subjected to destructive distillation for the recovery of the volatiles, ammonia, kelp tar and combustible gas, and the formation of a residual charcoal to be leached for the extraction of potash salts and refined for the production of an activated decolorizing carbon. An operable method developed at this plant provided for the intermixture of concentrated Steffens waste and kelp before drying, and the subsequent processing of the two together. Thus the kelp was able to contribute its nitrogen to the ammonia produced, its organic volatiles to the tar products, its potash to the total there obtained, and its fixed carbon to the final and main product, decolorizing carbon, without materially adding to the cost of operation. The process was designed to afford an outlet for the Steffens waste produced in southern California within a shipping radius of the kelp plants then in operation or subsequently to be built.

This method indicates the feasibility of treating this material in an analogous manner, by intermixture with some absorbent such as sawdust, instead of kelp, and processing as described. The future demand for activated carbons may justify such a procedure, particularly if central plants are established to dispose of the waste from a number

of sugar mills, thus making large-scale operations possible. Carbons produced in such a manner may prove to be useful reagents in sugar mills, even where the Steffens process is employed.

At Dessau, in Germany, Steffens waste has been utilized for years by a process, so far undisclosed, which yields cyanides and other products and is generally understood to be entirely successful from the point of view of profits.



Distillery Waste Evaporators, U. S. Industrial Chemical Co.

Future researches should be directed along organic lines, as the best promise of enhanced economics would seem to reside in the more profitable utilization of the organic compounds present in this material.

POTASH AS A BY-PRODUCT OF THE ALCOHOL INDUSTRY

In those industrial alcohol plants where molasses is fermented as the raw material, the residual solution still con-

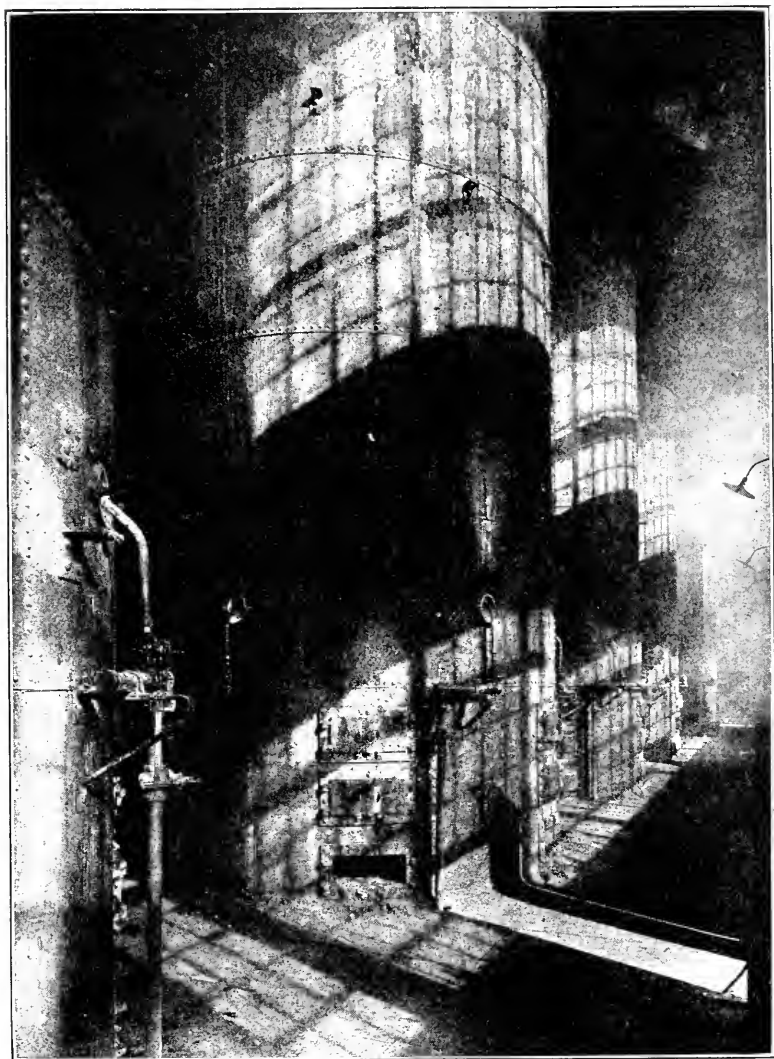
tains the potash and nitrogen present in the original molasses. Here again, the restrictions imposed on disposal in streams, harbors, or sewage systems make methods of disposal of economic importance, and force utilization. The main difficulty here, as in the case of Steffens waste, is the high cost of evaporation. After that, the recovery of values is relatively simple. Distilleries may operate in large units and continuously, and are accordingly in a position to operate by-product potash plants of fair size and capacity, with consequently greater economies. Methods of recovery have already reached a high state of efficiency; and the increasing importance of alcohol as an industrial reagent and motor fuel offers stability and the promise of an increased growth of that industry with increased potash potentialities.

QUANTITIES AVAILABLE

During a recent year 148,000,000 gallons of molasses were utilized by the American alcohol industries. This molasses, for the most part derived from the cane-sugar industry, has a content of mineral matter of about 1.25 pounds per gallon, containing 35 per cent potash. In this volume of molasses, therefore, there is contained approximately 32,000 tons actual potash, which is the quantity now made available by the distilling industry, but for the most part still thrown away and lost to agriculture.

The molasses consumed by this industry is greatly in excess of domestic production, requiring importation from contiguous sugar-producing territory. In forecasting possible developments, therefore, it is necessary to consider all of this territory, and to regard the molasses there produced as available raw material for the American industry. The demand for motor fuel in the neighboring sugar-producing countries, and the present high prices for gasoline now prevailing there, may result in the establishment of alcohol plants in the vicinity of the sugar mills, or even as a conventional part of the sugar mill itself. In this case the

molasses will not be available for use within the United States, and the potash conserved there will be used locally.



Distillery Waste Incinerators, U. S. Industrial Chemical Co.

These sugar mills produce from 5000 gallons molasses per day in the smaller, to 20,000 gallons in the larger.

In view of the fact that the fertilizers used in these territories are supplied largely by the United States, such potash may be regarded as a contribution to the American supply. This consideration, however, is based on the further supposition that potash recovery will be developed to such a point that its economic attractiveness compels its adoption.

Production of Cane Molasses in the Americas.—In the manufacture of sugar from sugar cane, the yield is 9 to 10 per cent of the weight of the cane. This is attended by the production of 30 per cent by weight of final or waste molasses, equivalent to 50 to 60 gallons per ton of sugar, or 5 to 6 gallons per ton of cane, on the basis of 12 pounds per gallon. Less efficient operation results in a greater production of molasses.

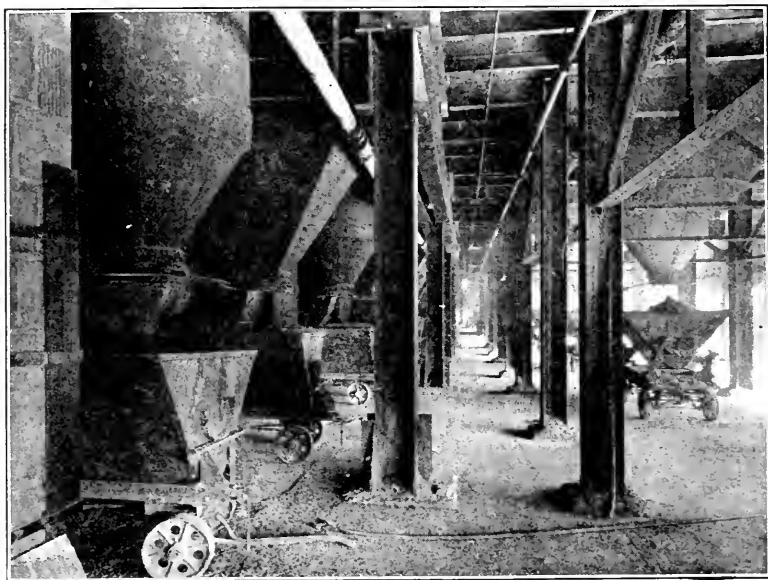
The sugar crop of the Americas is placed at 6 to 7 million tons. On this basis the amount of molasses here produced is about 350,000,000 gallons. This is equivalent to more than 400,000 tons of ash containing 35 per cent potash, or 140,000 tons actual potash.

METHODS OF RECOVERY

The Whitaker Process.—The most successful process for the recovery of potash from distillery waste, and the one representing the greatest advance in that technology, is the process employed in the Baltimore plant of the U. S. Industrial Chemical Company, and designed by Dr. M. C. Whitaker, the president. It provides not only for the recovery of potash, but also for that of ammonia, and thus yields two essential fertilizer ingredients.

In the manufacture of alcohol from molasses, before fermentation is started the molasses is diluted by the addition of 5 to 6 gallons of water to each gallon of molasses. The residue, after the alcohol has been distilled off, is a dilute solution of the non-sugars and inorganic salts originally present. At the plant mentioned, there is a daily accumulation of approximately 1,000,000 gallons of this waste mate-

rial. This is subjected to a preliminary evaporation and concentration from an originally dilute solution to a concentration in organic constituents such that it is able to support its own combustion. At this stage it is sprayed into a combustion chamber through spray nozzles directed upward. The droplets of solution are desiccated in the hot gases of the furnace, and as they fall toward the hearth are burned, and the residual particles of incombustible matter



Potash Discharging Hoppers, U. S. Industrial Chemical Co.

accumulate on the hearth to form a sintered mass of potash. This is cooled, ground, and shipped to market.

The hot gases pass out at the top of the combustion chambers at a temperature of 1200°C ., through dust-settling chambers, and thence into waste-heat boilers. The cooled gases are then led through Cottrell precipitators for final cleansing, and then through ammonia absorption apparatus for the recovery of ammonia as the sulphate. Thus are obtained the potash and ammonia, and the fuel value of the

organic matter is utilized, representing a high degree of conservation of the values contained therein.

In the following table is given an analysis of the potash obtained as a by-product of the alcohol industry:

TABLE XXXVI

POTASH FROM DISTILLERY WASTE AS PRODUCED BY THE U. S. INDUSTRIAL CHEMICAL Co.

Analysis of a Composite Sample Representing 100 Carloads

| | Per Cent |
|--|----------|
| Moisture at 100° C..... | .17 |
| Insoluble in acid before ignition..... | 5.82 |
| Iron and Aluminium oxides ($\text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3$)..... | 6.40 |
| Lime (CaO)..... | 16.08 |
| Magnesia (MgO)..... | 4.80 |
| Manganese oxide (MnO_2)..... | Trace |
| Potash (K_2O sol. in dil. HCl)..... | 34.72 |
| Potash (K_2O , water sol.)..... | 33.88 |
| Total phosphoric acid (P_2O_5)..... | 2.16 |
| Insoluble phosphoric acid (P_2O_5)..... | .47 |
| Citrate-soluble phosphoric acid (Available P_2O_5)..... | 1.69 |
| Nitrogen (N)..... | .30 |
| Equiv. NH_3 | .36 |
| Carbonate (as CO_2)..... | 8.10 |
| Total sulphur (as SO_3)..... | 12.50 |
| Chlorides (as Cl)..... | 8.91 |

The present production at this plant is about 50 tons of potash salts and 10 tons of ammonium sulphate per day.

POTASH FROM INDUSTRIAL WASTES—BY-PRODUCT POTASH—INORGANIC

POTASH FROM BLAST-FURNACE DUST

Blast-furnace dust as a source of by-product potash has received expert attention in this and other countries, particularly during the war years of potash scarcity. However, the problem of extraction has not been reduced to such terms as to bring about the general introduction of potash recovery into the blast-furnace industry.

Fortunately for the good of the proposal that the great tonnage of potash here available be conserved, there are excellent arguments based on uncontested facts, entirely aside from the relatively small value of the potash to be recovered in any single plant. These arguments, which should prevail to bring about the installation of potash-recovery systems, have to do with the conservation of heat and the economies resulting from the use of thoroughly cleansed gas as contrasted with gas carrying a burden of



Potash Storage, U. S. Industrial Chemical Co.

dust. The cleaning of blast-furnace gas is essential, and gas cleaners are an important adjunct of every blast-furnace installation. For the most part, unfortunately, they are cleaners involving the use of water sprays, which result in a great loss of heat; and in such the potash is dissolved to form a very dilute solution and is consequently lost. Therefore, these cleaners do not in any respect meet the arguments advanced in favor of the modern and efficient dry methods of dust cleansing which eliminate the use of water sprays. The plants equipped with the latter, however, are very few in number, just as in the cement industry the plants equipped with dust-control apparatus constitute a small minority.

There is, accordingly, the prospect of a thorough demonstration of an entirely satisfactory method of effecting all the economies inherent in dry cleansing of blast-furnace gases. It is to be expected that this method, when once fully demonstrated, will so commend itself to the industry that it will be universally installed. The recovery of the great quantity of potash annually lost in present practice will thus be realized.

THE ORIGIN OF THE POTASH IN BLAST-FURNACE GASES

In all of the raw materials entering into and making up the charge of the blast furnace, there are small quantities of potash. The charge of iron ore, the fluxes, such as limestone, and the fuel, coke, all contribute their small quota of potash to the total entering the furnace—small in proportion to the total weights, but large in the aggregate, as the tonnage of materials entering the average furnace is very great. In the heat of the furnace and in the reactions there taking place, the potash is volatilized and a portion of it is swept from the furnace by the stream of gases issuing therefrom. The balance, constituting the major portion, is eliminated in the slag.

QUANTITIES

The Bureau of Soils Survey.—The following table, arranged by Messrs. Merz and Ross of the Bureau of Soils, and based on their surveys,¹ shows the average distribution of the potash among the raw materials entering the furnace and the products discharged therefrom.

It will be observed that the average potash content for the ore used in this industry is low, being only 0.17 per cent. Since the bulk of the ore comes from the great deposits of the Lake Superior region, and since that ore is remarkably free from potash, the average for the country is thus reduced.

¹ "The Recovery of Potash as a By-product in the Blast-furnace Industry," Dept. Bul. 1226, U. S. D. A.

The Southern ores, on the other hand, contain much higher percentages, twelve specimens from Alabama and Georgia, for example, showing an average of 0.51 per cent. While only 6 million tons of this ore are used, it is smelted at points centrally located in agricultural regions, into which large tonnages of potash are annually imported.

TABLE XXXVII

TOTAL QUANTITIES OF POTASH ENTERING THE BLAST FURNACES OF AMERICA
AND ITS DISTRIBUTION AMONG THE PRODUCTS

| Material | Annual Consump- tion,* Short Tons | Average Potash (K ₂ O) Content, Per Cent | Potash (K ₂ O) per Gross Ton of Pig Iron, Pounds | Total Potash (K ₂ O) Content, Short Tons |
|------------------------------------|--|---|---|---|
| Ore | 72,800,000 | 0.17 | 7.3 | 123,800 |
| Limestone | 18,400,000 | .16 | 1.7 | 29,400 |
| Coke | 38,700,000 | .18 | 4.1 | 69,700 |
| Total in charge | | | 13.1 | 222,900 |
| Pig iron | Production Gross Tons 33,700,000 | | | |
| Slag | Short Tons 23,600,000 | 0.59 | 8.2 | 139,200 |
| Total lost by volatilization | | | 4.9 | 83,700 |

* The figures for consumption and production of ore, limestone, coke, and pig iron are average values obtained from Annual Statistical Reports, American Iron and Steel Institute, 1913 to 1920. The production of slag was calculated from the ratios of slag to pig iron for numerous blast furnaces throughout the country.

It is a fortunate circumstance that this minute proportion of potash, distributed throughout a great mass of material entering the blast-furnace, can be concentrated in good part at one point and there be recovered in a simple and automatic manner.

The Bureau of Soils has made a thorough-going survey of the American blast-furnace industry to determine the amounts of potash involved therein, with a special view to ascertaining how much of that by-product is recover-

able from the industry as a whole. Messrs. Ross and Merz in this investigation secured representative samples of all the principal iron ores used in the American industry, and likewise of the limestones and dolomites and coke. They also obtained samples of the slag produced at the various furnaces. All of these were analyzed for their potash content. Having determined in this way the potash content of the materials entering the furnaces and of the slags discharged, and knowing the tonnages involved, these investigators were able to calculate by difference the potash evolved from the furnaces in the furnace gases and thus made available for recovery. On these results the foregoing table is based.

The results may be summarized in the statement that for each ton of pig iron produced an average of 13.1 pounds of potash is charged into the furnace and 4.9 pounds evolved with the furnace gases. On the basis of a yearly production of 33,700,000 tons of pig iron for the country, the amount of potash thus entering the furnaces is 223,000 tons, and that evolved is 83,700 tons actual potash. This is equivalent to 167,400 tons of a fertilizer grade of potassium muriate, and represents the quantity evolved without any effort whatever being made to increase volatilization.

Analyses were made also of numerous samples of blast-furnace dusts as collected from down-comers, flues, stoves, and boilers, and from other places where they were deposited incidentally in the gas-handling equipment. As is to be expected in the examination of such an assortment of materials, the potash content varied over very wide limits, from none in two instances to as high as 20 per cent actual potash. The two extremes serve to show how completely the dust proper and the potash fume evolved therewith may be separated, even where no effort is made to accomplish that end.¹

¹ Merz and Ross, *loc. cit.*, p. 7.

The bulletin here referred to contains a reference list of numerous articles pertaining to the subject of potash from the blast-furnace industry.

ECONOMIES RESULTING FROM THOROUGHLY CLEANED GASES

As stated by Hohl,¹ the principal advantages resulting from the use of clean gas are:

(1) Reduction in the cost of cleaning and repairing stoves.

(2) Higher blast temperatures, resulting in lowered coke practice, increased output, and cheaper pig iron.

(3) Saving in gas used by stoves, leaving more gas available for boiler and gas engine use.

It has been shown that in general practice from 10 to 14 per cent of all the heat generated within the blast furnace is carried therefrom by the gases evolved. In a blast furnace of a capacity of 500 tons per day, using 750 tons of coke, this heat is equivalent to from 75 to 100 tons of coke per day. Or, on the basis of tons of pig iron produced, it is equivalent to a saving of about 15 cents per ton (with coke at \$6 per ton). For the industry, then, producing 33,000,000 tons, there would be an annual economy expressed by the sum of approximately 5 million dollars. It is obvious, from this simple statement, that in the cleaning and handling of these gases it is important to employ those methods which will conserve as much as possible of this heat.

Against such great economies as here represented, no unworthy consideration should be permitted to prevail; and it is difficult to find any argument of sufficient weight to justify the perpetuation of methods which defeat this conservation. Competition within the industry should compel the adoption of this measure, which is now regarded with no inconsiderable indifference, and the rising price of coal may be expected to hasten it. With this conservation will come the further saving represented by the recovery of the potash now thrown away.

¹ G. M. Hohl, Bethlehem Steel Co., "The Cleaning of Blast Furnace Gas," before the American Iron & Steel Inst., New York, May 23, 1924.

METHODS

In the cleaning of blast-furnace gases, common practice prescribes the use of water sprays, and it is only within recent years that methods which eliminate the use of water have been developed. In the old methods, of course, the temperature of the gases is reduced, with the loss of the heat burden carried by them; the gases are imperfectly cleansed; entrained water spray is carried along and causes trouble in other parts of the equipment; and the gases become diluted with water vapor. The water discharged from the cleaners carries its burden of dust of 10 to 15 tons per day, and to recover this an installation of thickeners and filters and auxiliary equipment must be provided. Their operation constitutes the sludge nuisance.

An inadequacy of water supply contributes a further disadvantage, since 30 to 35 gallons are required for each 1000 cubic feet of gas treated. The elimination of wet methods and the substitution of the dry represent so many advantages and economies of importance as to commend itself in imperative terms to every blast-furnace engineer.

The dry methods suggested, and for the most part demonstrated, for cleaning blast-furnace gases, are based on three different principles: filtration, as represented by the Kling-Weidlein process, in which mats of steel wool are used as the filter medium; gravitational and centrifugal methods, the deposition of suspended dust particles through a sudden and violent change in direction of gas flow, as developed by the By-product Recoveries Company; and the deposition of suspended dust and fume particles by electro-static methods, as illustrated by the well-known Cottrell precipitator and as ably presented to the technical public by the Research Corporation.

Since the electrical method is the one that has been used most successfully in the precipitation and recovery of potash fume, it is the one that, from the point of view of the present

discussion, is of greatest importance. While other methods make possible the conservation of heat and the realization of other great economies resulting from the use of dry methods as contrasted with wet, this is apparently the only process that offers facilities for the efficient recovery of potash in concentrated form. It is accordingly given emphasis.

The present trend of results obtained in a study of this problem indicates that it may prove advantageous to apply a two-stage precipitation: one stage employing gravity methods to remove the bulk of, and coarser portion of, the dust; and the second, an electrical precipitator, to effect the final cleaning with the removal of the potash fume. This would serve the double purpose of lessening the burden on the electrical precipitator, enabling it to function more effectively in removing the last of the suspended impurities, giving a purer gas, and of yielding a product richer in potash. Recent developments, however, in the electrical precipitator, as applied in the cement industry for the recovery of cement dust and potash, are such as to offer the possibility of convenient fractional precipitation within the precipitator itself, yielding fractions of progressively increasing fineness and potash content.

The Cottrell Process.—The Cottrell precipitator, as presented by the Research Corporation, and as represented by former installations, is made up of units, each consisting of a steel shell, about 9 feet in diameter, containing 90 six-inch pipes 10 feet long, through the center of which a wire is suspended. Each unit has a capacity of 11,000 cubic feet of gas per minute, flowing at the rate of 10 feet per second at the pressure normally maintained in the main. Eight units are required to clean the gas from a 500-ton furnace.

The cleaning effect is obtained by passing gas, with its burden of dust, through an electrical field induced in each pipe by a corona discharge from the wire suspended therein. The gas is ionized, and the dust particles receive electrical charges which drive them against the walls of the pipe, where

they adhere as long as the current remains on. At regular intervals, the current is automatically turned off, and tapping hammers induce sufficient vibration to dislodge the dust and cause it to fall into hoppers below.

Current for inducing the corona discharge may be obtained by stepping up ordinary 220- or 440-volt, 25- or 60-cycle current to a voltage of 35,000 to 40,000 volts by means of a specially designed transformer, and converting the alternating to unidirectional current by means of a mechanical rectifier. To clean all the gas from a 500-ton furnace, a power consumption of about 60 k.w. is required, or about 0.1 watt per 1000 cubic feet.

In wet washing, the dust content is reduced from 2 to 3 grains per cubic foot to 0.20 to 0.25 grain. The electrical precipitator has been shown to give efficiencies as high as 97 per cent and to yield gases containing as low as 0.1 grain per cubic foot.

The Cottrell precipitator, as applied to blast-furnace gases, has been successfully demonstrated at Dunbar and Sheridan, Pa., and at other places, and in its improved form has been installed by the Colorado Fuel and Iron Co., at their Minnequa Works, Pueblo, Colo.

COMPOSITION OF BLAST-FURNACE POTASH

The potash evolved from the blast furnace is recoverable as the sulphate, if no chemical reagent is added to the charge to alter its chemical composition. In the presence of chlorides, however, the potash is evolved as the chloride. Where blast-furnace dust has been leached and the resulting brine evaporated for the crystallization of potash salts, a high-grade sulphate has resulted, as shown by the following analysis of the salts produced by the Lavino Furnace Co., Sheridan, Pa.

TABLE XXXVIII

COMPOSITION OF BLAST FURNACE POTASH AS PRODUCED BY THE LAVINO FURNACE CO., SHERIDAN, PA.

| | Per Cent |
|---------------------------------------|----------|
| Potash (K_2O)..... | 47.95 |
| Sodium oxide (Na_2O)..... | 5.28 |
| Sulphur trioxide (SO_3)..... | 47.59 |
| Chlorine (Cl) | none |
| <hr/> | |
| Total..... | 100.82 |
| Potassium sulphate (K_2SO_4)..... | 88.70 |

COSTS

The question of costs of producing potash as a by-product of the blast-furnace industry must be determined in the manner usually adopted for determining the cost of by-products. Fortunately, the conservation of potash in this instance is accompanied by other economies of such magnitude as to commend that practice to all blast-furnace engineers. Since the cost of installation and operation of a potash-recovery plant would be chargeable against pig-iron production the potash itself would have to carry only those costs involved in its manipulation after it is removed from the precipitator. What these costs are will be determined by the concentration of potash in the dust, whether or not it will have to undergo additional concentration and its storage, sacking and transportation costs. Blast-furnace potash has been yielded commonly in concentrations of about 15 per cent, comparable in that respect to the German kainite, formerly a popular grade of potash for use in mixed fertilizers. The present tendency in the fertilizer industry, however, is toward high-analysis, and even concentrated, fertilizers; and the high freight rates now prevailing restrict the market for such a product to regions contiguous to the point of production—considerations which increase the desirability of producing the potash directly in as high a concentration as possible. Leaching

with water that portion of the dust which is richest in potash and subsequent crystallization of high-grade potash, with the use of modern and improved methods of counter-current leaching, evaporating and crystallizing, may prove desirable; but the success of the by-product would certainly be promoted if some method were employed to produce concentrated potash directly. Such a method would be analogous to that in successful use at the Davenport plant of the Santa Cruz Portland Cement Company, to be described in a later paragraph, where, by the preliminary mechanical separation of all the coarser dust, the electrical precipitator brings down principally the potash fume to form potash salts of such high concentration that they can be marketed directly. Simple mechanical dust settlers, placed in front of the electrical treater to remove about 75 per cent of the dust, should permit only the finer dust and potash fume to enter the electrical precipitator, which should then yield a product correspondingly higher in potash content. This would not add materially to the cost of operation, and would remove all necessity for further concentration.

CHEMICAL METHODS OF INCREASING POTASH YIELDS

The potash evolved from the blast furnace, as has been observed, is only that portion which does not enter the slag as silicates. The higher the potash content of the charge, the greater the quantity that enters the slag, indicating the existence of equilibria. Accordingly, any constituent which increases the volatility of the potash, or which may be substituted for it, may increase the quantity evolved. Common salt carries both chlorine, to combine with potash to form one of its most volatile compounds, and sodium, which is capable of substituting most readily for potash in most reactions; it also possesses the advantage of cheapness. It therefore suggests itself as a most favorable reagent for this purpose and has been subjected to test to determine its efficacy in inducing potash volatilization. The results, as obtained in

England during the war years, are best presented in the following quotation from Chance.¹

The North Lincolnshire Iron Co., Ltd., consented to try the experiment of adding salt to one of their furnaces in sufficient quantities to volatilize the whole of the potash in the furnace. This was done in February, 1917, and the success was instantaneous, the chlorides in the gas rising from about 30 pounds per million cubic feet to upwards of 200 pounds expressed as potassium chloride, while the proportion of potash to soda in the total chlorides was not decreased, but remained at about 9 to 1 and the alkali in the gas was unaffected. The actual potash in the gas as alkalies and chlorides combined was therefore raised from about 60 pounds to upwards of 200 pounds per million cubic feet of gas.

The use of salt has been repeated in several blast furnaces in other parts of the country since that time and, while the quantity of potash volatilized naturally varies with the quantity charged into the furnace, in no case has the addition of salt failed to more than double the quantity of potash found in the gas while in others it has trebled or quadrupled it. (See Eng. Pat. 112,338 of 1917.)

The extended use of salt in blast furnaces has up to the present disclosed, so far as I am aware, no adverse results as regards the manufacture of pig iron.

The potential value of such simple methods of increasing potash yields, when the practice of potash recovery from blast furnaces has been generally instituted, is at once apparent. As applied to American conditions, to double the present quantity of recoverable potash would raise that amount from the present 83,000 tons to 166,000 tons, and the limiting quantity to approximately 200,000 tons actual potash per annum.

¹ "The Effect of Adding Salt to the Charge on the Liberation of Potash from the Blast Furnace," by Kenneth M. Chance, *J. Soc. Chem. Ind.*, **37**, 222 T. (1918); also, *ibid.*, p. 88 A.

POTASH FROM CEMENT DUST

FOREWORD

Cement-mill flue dust is now recognized as a very important potential source of potash. As a by-product, potash can be produced therefrom without adversely affecting in any way the quality of the principal product or materially altering the methods of its manufacture. The dust and its burden of potash are by nature waste products. In many instances dust recovery is imperative, and the necessity for such practice is constantly becoming more general and more pressing. The dust recovered has value as raw material and more, since it is raw material both ground and partly burned. Its recovery represents a cost which may be neutralized to a large degree by the value assigned it as raw material. To this may be added any value assigned to the good will of the community through dust elimination. It is at this point that the computation of charges against potash recovery should begin.

Dust recovery by the electrical precipitator of the Cottrell type seems to have been reduced more completely to engineering terms, and its use more completely standardized, than recovery by any other equipment. In its latest form of horizontal plates and consequently larger areas of activity, coupled with facilities for accurate draught control, forced draught, and the elimination of stacks, and with the waste-heat boilers which are a concomitant of ideal installations—dust recovery is a direct aid to efficient operation and is a mark, if not an essential, of good engineering practice. Increased production and a more uniform and higher grade of cement, made possible by a more exact control of draught and temperatures within the kilns, are directly attributed to dust-recovery apparatus. Economizers for the production of power through the utilization of the large quantity of heat carried by the waste gases from the kilns have completely

demonstrated their value and are now enjoying well-merited popularity. The present tendency is to adopt this combination of waste-heat boilers and dust precipitators as a conventional part of up-to-date cement-mill construction.

Potash recovery is but a single step further and will yield a return entirely commensurate with the other aforementioned measures so eminently recommended by good engineering practice. Opinion within the industry, however, has not yet recovered from the disappointments occasioned by the set-back given this and all other American potash projects by the unfavorable condition of the potash market which followed the close of the World War.

The apparent failure of certain methods which were applied to the production of high-grade potash salts during the war years, while undoubtedly discouraging to those interested, will have but little permanent effect upon the industry. Many unforeseen difficulties were met and were not immediately overcome. Temporary set-backs of this nature are to be expected in new enterprises. They merely delay, rather than prevent, development. Out of the confusion of the strenuous war years there has emerged a clearer conception of the nature of the materials and problems involved. There still remains something to be learned concerning important phases of the problem. Yet such progress has been made that certain attempts to recover potash have been entirely successful. While quantity production is small, the fact that in one cement plant potash is being produced at a profit under present adverse market conditions means that it ultimately will be so produced in all plants. The general adoption of recovery systems awaits only the development of more satisfactory methods, or the elimination of defects in present methods, and further proof of the continued success of the methods now in use. The fact that the successful method is still imperfect is an argument in favor of the general proposal, not against it.

NATURE OF CEMENT DUST AND POTASH FUME

Any methods suggested or attempted for potash recovery should be based on a thorough understanding of the nature of the material involved, and the essential differences between the potash salts and the inert material in the dusts recovered from the flue gases from which the potash must be separated. The bulk of the dust is composed of fine particles of the raw mix charged into the kilns. These particles are mechanically picked up and carried by the blast. Potash, on the other hand, is volatilized in the hottest portion of the kiln, and enters the gas stream in the form of a vapor which later condenses to the solid state. There is, therefore, a vast difference in the size of the particles. In the recovered dusts the particles are coated with the condensed potash fume. Whether this is due entirely to condensation, or in part at least to electrical precipitation has not been definitely determined. Certain it is that a dust richer in potash is obtained by electrical precipitation than by any other means yet applied. This may be due to a more complete recovery of the finer dust particles, which by virtue of a larger aggregate surface area are richer in potash. If the dust is largely removed by some preliminary operation and only the finest particles are recovered by electrical precipitation, a material richer in potash is obtained.

Size of Particles.—The size of the dust particles is such that practically all of them readily pass a 200-mesh sieve. As measured under the microscope,¹ the sizes range from about .15 mm. down to the less than .0025 mm. in diameter, the upper and lower limits, however, varying somewhat with various operating conditions. The above measurements obviously do not apply to the potash fume.

Properties.—When oil is used as fuel, the flue dust is almost white, while flue dust from coal-fired kilns ranges from

¹ Through the esteemed courtesy of Mr. W. H. Fry, Petrographer of the Bureau of Soils.

gray to black, the color being due to and depending upon the amount of unburned carbon present.

There is also a marked difference in the relative solubility of the potash in the dusts obtained from oil-fired and coal-fired kilns. Except for a small fraction which is originally present in the dust particles and which remains unaffected, practically the entire amount of potash contained in dusts from oil-fired kilns is readily soluble in water. In the dusts from coal-fired kilns, however, a varying proportion of the potash, about 25 per cent, is slowly soluble in water, though readily soluble in dilute acids. Opinions differ as to the true explanation of this difference in behavior. It has been attributed to several causes which need not be elaborated here. It does not appear to be an insuperable or even a serious difficulty; in fact there is no evidence to indicate that the acid-soluble potash, which is but slowly soluble in water, is not available as plant food, and there are some reasons for assuming that it is.

The question of utilization, however, is not a paramount one. Production is dependent upon obtaining the potash in a sufficiently high concentration to bear the cost of transportation to the nearest available market. It is toward concentration, therefore, that attention must be directed, although the impurities on the whole are more beneficial than injurious for agricultural purposes, and except from the point of view of dilution, are not objectionable.

QUANTITIES OF POTASH AVAILABLE FROM CEMENT DUST

The Bureau of Soils Survey.—A comprehensive survey of the American cement industry from the point of view of potential potash production has been made by W. H. Ross, A. R. Merz, and C. R. Wagner of the Bureau of Soils.¹ Representative samples of raw mix and ground clinker

¹ "The Recovery of Potash as a By-product in the Cement Industry," U. S. A. Bul. No. 572.

were obtained from 104 plants in the United States and 9 plants in Canada, and were analyzed for potash. It was found that the potash content of the raw mix from the different plants varied from .20 to 1.16 per cent; that for 96 plants, or 85 per cent of the total number, it was not below .50 per cent and the average was .70 per cent actual potash. The amount of potash volatilized varied from 24.5 to 95.9 per cent of that contained in the raw mix. The average for all plants was 46.6 per cent; and for 71 plants, or 60 per cent of the total number, the amount volatilized was 40 per cent or more of that present.

The average amount of raw mix required to produce one barrel of cement is approximately 600 pounds. An average production of 90,000,000 barrels of cement per annum would thus yield from 85,000 to 90,000 tons of actual potash.

The amount of potash volatilized per barrel of cement produced varies from less than one pound in certain cases where blast-furnace slag is used as raw material, to more than 5 pounds in another instance where raw material fairly rich in potash is used and a relatively high percentage of the potash present is volatilized. The average for all plants is 1.93 pounds. Omitting those plants producing less than one pound per barrel and the 9 Canadian plants, the average for the 99 remaining plants in this country is 2.09 pounds of potash per barrel of cement.

The average estimated per cent of potash in the flue dust of 92 of the above 99 plants is 10.26. The 7 plants omitted from this average showed less than 5 per cent potash in the dust.

It has been demonstrated commercially that 90 per cent of the potash escaping in the dust is recoverable and from experiments made in the laboratory it would appear that 95 per cent of the recoverable potash is, or may readily be made, available.

Assuming, in the light of results that have already been obtained, that it would be practicable to increase the percentage of potash volatilized to at least 65 per cent of all plants, then the available recoverable potash would amount

to more than 100,000 tons annually, or to nearly one-half of the normal consumption of potash in this country.¹

A survey as thorough as that outlined above removes most of the elements of a speculative nature and reduces the problem to one in which concrete facts may be taken as the basis of procedure.

METHODS OF RECOVERING POTASH FROM CEMENT DUST

Following the discovery, at the plant of the Riverside Portland Cement Company, at Riverside, Calif., that in the precipitation of cement dust by the Cottrell precipitator workable quantities of potash were simultaneously recovered, and under the impetus of the very high prices for potash of the war years, the recovery of potash as a by-product of the cement industry was undertaken, not only at the Riverside plant, but also at some eight other plants situated at various points in the United States. While most of them employed the electrical precipitator, with good success, others attempted water-spray methods of recovery.

The serious aspects of the problem were found to lie not in the initial precipitation of the dust and potash fume, but rather in their separation. This called for more of deliberative research than the exigencies of the times permitted. Haste was imperative in order that advantage might be taken of the highly beneficial market. The consequence was that installations for large-scale operation were constructed without the foundation of a thorough understanding of the principles involved, and a disappointing performance resulted. There was not sufficient time in which to solve all of these problems before the rapid decrease in potash prices removed the incentive for further research. Thus, the general problem of potash recovery from cement dust was left in a very unsatisfactory state. The disappointments resulting made a deeper impression than the successes.

¹ Ross, Merz, and Wagner, *loc. cit.*

In some instances, notably that of the Security Cement & Lime Company, no attempt to concentrate the potash of cement dust was made, beyond that induced by a direct fractional precipitation of the dust in the recovery system. The richest potash material thus obtained, containing 21 per cent potassium sulphate, was sold directly for fertilizer purposes, the balance being returned to the process as raw material. The simplicity of this procedure has much to commend it and to invite investigation for its development to a higher state of efficiency.

Methods of obtaining high-grade potash through reburning the mixture of recovered dust and potash fume, while yielding a high-grade product, were not economical because only about 20 per cent of the potash was recovered, the remainder going into the clinker as non-volatile compounds.

The Cottrell Process.—The electrical precipitation of dust and fume by the method based on the Cottrell patents and as presented by the Western Precipitation Company, has been described too often and too well to need any further elaboration here. It is at present foremost among dry methods of precipitation. Its popularity and success have made possible its rapid development and improvement. It is already in a high state of development, and promise is now being fulfilled of a further radical improvement in efficiency and reduction in cost, which should greatly broaden its field of usefulness. This new development is of particular interest to the cement industry, where the low value of the dust collected makes a low cost of installation of dust-collecting apparatus imperative.

Water-spray Methods.—When, to recover potash from cement dust, leaching with water was the accepted procedure, it appeared logical to use water spray to recover the dust and fume directly and to dissolve the potash simultaneously. Wet methods of precipitation, therefore, received much expert attention. Under this impetus several methods were developed and applied with fair success.

The Fleming system ¹ prescribes the exhaustion of the gases from individual kilns by means of fans which discharge through connecting flues into a large dry-settling chamber. The volume of gases to be handled in such a system, on the basis of the average for the country, is 15,000 cubic feet per barrel of cement produced, and this volume is frequently diluted 100–500 per cent with air drawn into the system from outside. In this chamber the speed of the gases is reduced 90–95 per cent, resulting in a deposition of about two-thirds of the dust. Following this are wet-settling chambers, with transverse baffle partitions alternately rising from the floor and descending from the ceiling. Each section is equipped with sprays. The spent water with its burden of dissolved salts and suspended solids is delivered to settling tanks and, relieved of its solids, is returned to the system and recirculated until its concentration in dissolved salts is equivalent to one-half pound per cubic foot. No general measure is given of the efficiency of the process as a means of recovering potash.

At the Victorville, Calif., plant of the Southwestern Portland Cement Company,² this method of dust and potash recovery was employed. In order to bring about a more complete precipitation of the fume, the emerging gases, saturated with water vapor, were cooled below the dew point to induce the deposition of water upon the particles of potash fume functioning as nuclei of precipitation. The potash brine subsequently to be evaporated was used as the agent of heat transfer to effect this cooling.

However, despite these special efforts to recover the last of the potash fume, it was found, when the emerging gases were passed through an electrical precipitator, that more potash was there recovered. These results indicate that it is difficult to precipitate potash fume completely with water

¹ "The Fleming Dust Collecting System," by W. C. Hanna, Chem. and Met. Eng., **13**, 609 (1915).

² "A Wet Process for Extracting Potash from Cement Dust," J. G. Dean, Chem. and Met. Eng., **19**, 439 (1918).

spray. "It was early found that the largest excess of water dripping through dusty gases failed to wet and precipitate satisfactory amounts of solids rich in potassium."¹

The Krarup Process of the Santa Cruz Portland Cement Company.—Another and a very successful development of this system is that installed and operated by the Santa Cruz Portland Cement Company, at Davenport, Calif. As this process represents the most successful and noteworthy effort to produce potash from cement dust, it deserves especial attention.²

The Krarup process involves the essentials of both the wet and the dry methods, and is based on the fundamental principle of precipitating the cement dust proper separately from the potash fume and in the order named.

To accomplish this purpose, the kiln gases with their burden of dust and fume are drawn downward through a spray tower and discharged into a dry-settling chamber, and thence upward into an electrical precipitator. The draught is maintained by a fan placed beyond the precipitator. The system is accordingly maintained under some slight vacuum. The gases enter the system from an opening near the top of the kiln stack.

As the dry process of cement manufacture is used here and as waste-heat boilers have not yet been installed, the temperature of the issuing gases is about 750° C. It is accordingly necessary to cool them. The water sprays serve the dual purpose of reducing the temperature to about 100° C. and of precipitating the major portion of the dust. This is accomplished without saturating the gases with water-vapor. Approximately 75 gallons of water is circulated per minute for each kiln, of which about 20 gallons is evaporated. The spray tower is 21 feet high and 6 by 10 feet in cross-section. At each 7-foot level is placed a horizontal baffle which leaves an opening 4 by 6 feet. Spray and

¹ Dean, *loc. cit.*

² Cf. "The Successful Recovery of Potash as a By-product from Cement Kilns," by B. C. Krarup, *Chem. and Met. Eng.*, **25**, 316 (1921).

dust descend together, about 95 per cent of the dust being entrained from a stream of gases of about 35,000 cubic feet per minute.

The dry dust-settling chamber, 13 feet wide, 30 feet long and 7 feet high, is situated directly beneath the electrical precipitator but is separated therefrom by a horizontal partition, around the sides of which the gases pass to enter the precipitator above.

The electrical precipitator is contained in a chamber 13 feet wide and 34 feet long. The horizontal partition beneath carries a belt conveyor running the length of it to receive the potash falling from the precipitator above. This discharges upon rolls which deliver the potash automatically and continuously, directly into sackers situated outside of the chamber.

The precipitator is of the plate-and-wire type and is arranged as a horizontal grid. It is 12 feet wide and 30 feet long, with plates 18 inches wide, in the direction of gas flow, placed 6 inches apart. Discharge electrodes of wire are suspended, two between each two plates, 8 inches apart and one above the other. A mechanical knocking device, operated once an hour, serves to keep the discharge electrodes free from the accumulated potash.

A recovery efficiency of 70 to 80 per cent of the potash is claimed. The product is light and fluffy as it falls from the precipitator. The rolls through which it is discharged to the outside serve the double purpose of compressing it to a more compact state and of preventing the inflow of air at the point of discharge. About 10 tons of potash salts has been the daily output.

COMPOSITION OF THE PRODUCT

The following analysis of Santa Cruz potash illustrates the excellence of the product. The potash being present as sulphate, the product enjoys an especial demand due to the

greater popularity of that potash salt, particularly in the western market.

TABLE XXXIX

ANALYSIS OF SANTA CRUZ POTASH *

| | Per Cent |
|--|----------|
| Potash (K_2O)..... | 31.25 |
| Sodium oxide (Na_2O)..... | 10.13 |
| Lime (CaO)..... | 8.68 |
| Silica and phosphoric acid ($SiO_2 \cdot P_2O_5$)..... | 2.48 |
| Sulphur trioxide (SO_3)..... | 45.47 |
| Chlorine (Cl)..... | 0.47 |
| Volatile (CO_2 , etc.)..... | 1.0 |
| Water (H_2O)..... | 0.52 |

* Supplied by the Santa Cruz Portland Cement Co., under date of July 7, 1924.

It will be observed that this product, as obtained directly from the precipitator and without any further treatment, compares favorably with the potash salts found in commerce, and in concentration greatly exceeds the bulk of them.

The question has arisen, in connection with the operation of the Krarup process, whether the potash there obtained is not the product of evaporation of the potash-bearing spray, the conditions being rather favorable to the complete desiccation of the finest particles of spray and the deposition of the product in the precipitator. However, a comparison of the composition of the circulating water with that of the precipitated salts shows too high a proportion of calcium in the latter to support that contention. Those operating the system are of the opinion that the potash recovered is the result of the direct precipitation of the potash fume, and the evidence at hand seems to be entirely favorable to that position.

The water from the spray towers, with its burden of cement material, is run into Dorr thickeners, from which both the water and the recovered solids are returned to the system. Amounts of potash representing a very low concentration are carried by this water. Likewise any other

of the constituents of the cement dust that are soluble in water go into solution.

The total concentration in these dissolved salts reaches 2 to 3 per cent, of which 0.06 to 0.09 per cent is calcium (calculated to CaO). Calcium and sulphate ions thus accumulate to a degree representing saturation with respect to calcium sulphate. That troublesome salt accordingly precipitates and builds up crusts of scale in pipe lines and apparatus, and results in annoyance and loss of efficiency. Its formation represents one of the most serious of the problems yet remaining to be solved in connection with this process.

The situation here found suggests the desirability of employing some dry substitute for the wet method of eliminating the bulk of the dust. With the substitution of waste-heat boilers to reduce temperatures and the elimination of water as the dust-settling agent it appears that the efficient recovery of potash from cement-kiln gases would be advanced to the ideal degree.

THE EXTRACTION OF POTASH FROM CEMENT DUST

Elaborate researches were conducted by the Riverside Portland Cement Company, at Riverside, Calif., to obtain potash of high analysis from the mixture of cement dust and precipitated potash fume as recovered by electrical precipitation. The efforts were meritorious and their success was marked.

In the process employed by this company the cement dust, in batches of 25,000 pounds, was leached for about forty-five minutes with water near the boiling point, resulting in a solution containing about 4.5 per cent actual potash. This was allowed to stand in shallow vats for the precipitation of gypsum and was then evaporated for the crystallization of potash salts. Because of the presence of the sodium ion and the preponderance of the sulphate ion, the product obtained was glazerite, the double sulphate of potassium

and sodium ($3\text{K}_2\text{SO}_4 \cdot \text{Na}_2\text{SO}_4$), analyzing approximately 80 per cent potassium sulphate and 20 per cent sodium sulphate. This system recovered 90 per cent of the potash contained in the dust.

Other plants reported production of potassium sulphate ranging from 38 to 47 per cent actual potash, and one, potassium chloride of 99 per cent purity.

Syngenite.—In the leaching of cement dust with water for the recovery of potash, difficulty was encountered in the earlier attempts on account of the interaction of the sulphates of potassium and calcium with the formation of the double salts, mono-calcium sulphate, syngenite,



and penta-calcium sulphate ($\text{K}_2\text{SO}_4 \cdot 5\text{CaSO}_4 \cdot \text{H}_2\text{O}$), which, forming precipitates, carried the potash out of solution and clogged the system with solids. In the presence of calcium sulphate they formed at low concentrations of potassium sulphate, and thus, in many cases, until their nature became better understood, operated to prevent the development of solutions high in potash concentrations. As a result of the comprehensive researches of Anderson,¹ it was shown that the leaching operations could be adjusted with respect to temperature, concentration, and time of contact with the solids, so as to avoid the complications due to the formation of those compounds. It was accepted as a satisfactory procedure to leach at temperatures above 85°C . and to confine the operation to less than one hour. The development of solutions of potash of high concentrations was not satisfactorily accomplished in large-scale plant operations.

The entire difficulty of double-salt formation is avoidable through the conversion of the system from one of sulphates to one of chlorides, by the use of sodium chloride added to the raw mix.

¹ "Double Salts of Calcium and Potassium and Their Occurrence in Leaching Cement Mill Flue Dust," *J. Ind. Eng. Chem.*, **11**, 327 (1919).

In the wet processes of dust and potash recovery, where it was originally hoped that high concentrations of potash could be developed in the circulating water used for spraying, the formation of these insoluble compounds presented an obstacle; and in all such operations the presence of calcium sulphate alone presented perhaps the greatest difficulty encountered, because of the readiness with which it formed deposits of crystals in pipe lines, spray nozzles, and in general on all exposed surfaces. Its convenient elimination from such solutions would represent a very substantial contribution to the technique of recovering potash from cement dust by wet methods.

METHODS OF INCREASING AMOUNT OF POTASH VOLATILIZED

To increase the potash output of cement mills, two general methods may be conveniently applied, namely, the use of potash-bearing minerals as part of the charge, and the addition of reagents to the charge to increase the amount of potash volatilized. Both may be used simultaneously, and their judicious use does not objectionably affect the chemical or physical properties of the cement. Both have been applied and found to be efficacious.

To increase the potash content of the charge, high-potash silicates, such as feldspar, shale, and greensand, are employed; and to increase the amount volatilized, sodium chloride and calcium fluoride are used. The location of a plant relative to a deposit of rich potash material will determine the economic feasibility of the first method. Sodium chloride, when added in the proportion of one per cent of the raw mix, has the effect of approximately doubling the amount of potash volatilized without increasing the alkali content of the finished cement. At the plant of the Security Cement and Lime Company, where the potash volatilized was normally about 38 per cent of that present in the charge, recovery was raised to about 65 per cent. In such cases the potash is recovered as chloride instead of as sulphate.

The Huber-Reath Calcium Fluoride Process.—To increase potash volatilization and recovery, a process was developed by Messrs. Huber and Reath and successfully applied at the Riverside Portland Cement Plant.¹ In this process, calcium fluoride as fluorspar was added to the raw mix in the proportion of 0.8 per cent for each one per cent potash present. The potash at 1100° C. reacts with the fluorspar and is converted into potassium fluoride, which is volatile at 850° C. This reacts with the gaseous oxides of sulphur to yield potassium sulphate, liberating hydrofluoric acid, which in turn reacts with the calcium present in the suspended dust and thus reverts to its original condition of calcium fluoride. As this is insoluble, on leaching it remains in the dust and therewith is returned to the system and thus is used repeatedly. Furthermore, any potash remaining in the dust through failure to become volatilized may be recovered in the second cycle. This method in practice increased potash volatilization from 60 per cent to 90 per cent.

Other Methods.—Other reagents designed for a similar purpose are calcium chloride, calcium oxychloride, sulphur dioxide, and steam. Increased volatilization may also be obtained by raising the temperature of the kiln or by increasing the proportion of limestone in the mix, the former measure resulting in a more complete burning of the charge and consequent improvement in the quality of the product.

Very important advances in the technique of potash recovery remain to be made. Fortunately they are in sight. The one of outstanding significance is probably the recent development of a much simpler, less expensive, and more efficient electrical precipitator, now being offered the industry by the Western Precipitation Company. The new equipment, it is reliably stated, has an installation cost of only about 25 per cent of that of the older types.

Waste-heat boilers, or economizers, as they are aptly

¹ Treanor, "Potash from Cement at the Riverside Portland Cement Plant," *Met. and Chem. Eng.*, **16**, 753 (1917).

called, while not exactly a part of potash-recovery equipment, constitute a valuable adjunct thereto in that they serve to lower the temperature of the effluent gases to a point where they can be more easily treated in the electrical precipitator, and to reduce their speed, resulting in the precipitation of the coarsest portion of the dust and in relieving the precipitator and accessory potash-recovery apparatus of a proportionate amount of work. These advantages are slight as compared with the greater benefit represented by the energy which waste-heat boilers conserve and which otherwise is wasted, an item of such importance that they will soon be conventionalized to the point where they will be regarded as an essential part of every cement plant.

It has been shown that where cement dust is precipitated in fractions determined by the size and weight of the particles, there is obtained a parallel fractionation of the potash. Thus, by separating the fine from the coarse particles, the potash may be largely concentrated in the former. Such a fractionation, based on size of particles, may be obtained in electrical precipitators if they be built in such a way that the gases pass through them in a horizontal direction. This is an advantage possessed by the latest and most improved form of precipitator.

Fractional precipitation of the dust may also be obtained by other apparatus, such as dust-settling chambers, cyclone separators, and, particularly, the equipment presented by the By-Product Recoveries Corporation. In this case the fractions rich in potash may be further treated to recover the potash, or may be sold directly as potash-bearing material, the remainder being returned to the kilns for reprocessing.

One possibility which as yet has not been thoroughly tested is the complete evaporation of the solution obtained by leaching the dust with water. This may be accomplished by spraying the solution into a chamber through which are passed the hot kiln gases, the waste heat being

thus further utilized. The desiccated material may then be recovered either by electrical precipitation or other means.

Elutriation.—To effect a separation of the potash fume from the dust proper, after the two have been precipitated together, air elutriation has been attempted. The experiments were conducted only on the laboratory scale. A sharp separation was not accomplished, but fractions were easily obtained which showed a marked increase in potash content over the original.¹

The concentration effected was apparently due to the segregation of the finer particles of dust. As will be shown, in the material tested, the potash appears to be fairly evenly condensed over the surface of the dust proper. The smaller particles, in the aggregate possessing a greater surface area, carry a greater percentage of potash.

The following table shows the parallelism between the potash content and the aggregate surface of the dust particles, where fractionation is based on size of particles. The fractionation was accomplished by elutriating with air at different velocities. The material employed was a typical dust, such as is obtained when dust and potash fume are precipitated together.

TABLE XL

THE POTASH CONTENT OF VARIOUS FRACTIONS OF DUST OBTAINED AT DIFFERENT AIR VELOCITIES

| Fraction Number | Air Velocity, Cm.-Min. | Per Cent of Dust in Fraction | Per Cent of Potash (K_2O) in Fraction | Per Cent of Total Potash (K_2O) in Fraction |
|-----------------|---------------------------|------------------------------------|---|--|
| 1 | 0 — 17.7 | 12.3 | 12.78 | 20.60 |
| 2 | 17.7 — 25 | 19.0 | 9.58 | 23.89 |
| 3 | 25 — 43 | 18.3 | 8.47 | 20.34 |
| 4 | 43 — 56 | 14.0 | 6.57 | 12.07 |
| 5 | Residue | 36.4 | 4.83 | 23.10 |

¹ "Potash from Cement Dust: Concentration by Elutriation," by E. J. Fox and C. W. Whittaker, *J. Ind. Eng. Chem.*, **15**, 1044 (1924).

From the preceding table, it is at once apparent that the higher percentages of potash are present in those fractions containing the smaller particles, and *vice versa*. This is interpreted as meaning that concentration is due to an increase in the aggregate surface per unit mass in the fraction containing the smaller particles. Applying Stokes' Law, it is seen that the size of the particles carried by an upward air current varies directly as the square root of the air velocity, whereas the aggregate surface contained in a unit mass of such particles varies inversely as the diameter of the particles. The aggregate surface contained in a unit mass of the dust obtained at a given air velocity is therefore proportional to the inverse square root of the air velocity. The following table shows that the variation in potash content of the different fractions is directly proportional to the aggregate surfaces in the fractions.

TABLE XLI
THE RATIO OF POTASH TO SURFACE IN CEMENT DUST

| Fraction Number | Air Velocity (V) | $\frac{1}{\sqrt{v}}$ | Potash Content | Potash Content $\frac{1}{\sqrt{v}}$ | Deviation from Average | Per Cent Deviation |
|-----------------|------------------|----------------------|----------------|-------------------------------------|------------------------|--------------------|
| 1 | 17.7 | .2370 | .1278 | .540 | .023 | 4.45 |
| 2 | 25 | .2000 | .0958 | .479 | -.038 | -7.35 |
| 3 | 43 | .1525 | .0847 | .556 | .039 | 7.54 |
| 4 | 56 | .1335 | .0657 | .493 | -.024 | -4.64 |

These observations indicate that cement dust may be obtained, by fractional precipitation of the dust, by subsequent elutriation, or otherwise, with a sufficiently high potash content to make further processing a much simpler matter, or to find a local market as a low-grade potash material without further treatment. There is no apparent reason why such fractionation should not be obtainable as a direct product of the process of precipitation. By such

practice a dust containing from 12 to 15 per cent actual potash, or higher, should be easily obtained. Such a product could be marketed in competition with German kainite and other low-grade potash salts, especially in the interior regions of the country. Arguments against the wisdom of attempting the marketing of low-grade potash are presented elsewhere in this paper. They apply here, likewise.

ECONOMIC ADVANTAGES POSSESSED BY CEMENT POTASH

The economy of modern fertilizer technique prescribes the use of more and more concentrated materials, principally to eliminate, as far as possible, the high costs of transportation which such products have to bear. The same considerations make it desirable to reduce the length of haul. Thus it is imperative that materials be produced in as great a purity as is compatible with other conditions which impose themselves, and that the product be used as close to the point of production as possible. Potash from cement has potentially the advantage of being able to meet these two requirements. It may be produced in high concentrations, and, since cement plants are widely distributed throughout the country, it should find a market "at the door," so to speak. An examination of the manner in which plants are distributed reveals the fact that 70 per cent of them are situated in states where the use of potash fertilizers is already generally established, and the balance in agricultural regions where it is presumed this condition will be realized at an early date. Eventually, with the readjustment of the factors determining costs, this product will possess a great economic advantage over the potash imported from foreign countries and will be able to maintain for itself a market in competition with potash from other American sources.

The potash now obtained at the Santa Cruz plant contains 32 per cent actual potash, comparable with the bulk of the potash now entering mixed fertilizers. It is obtained

in this remarkably high concentration directly from the flue gases, without subsequent treatment of any sort, and may be taken as typical of that which will be obtained from the other cement plants.

SUBTERRANEAN DEPOSITS OF POTASH SALTS

THE TEXAS DEPOSITS

The outstanding deposits of potash of the world, such as those formerly owned exclusively by Germany and now owned partly by the Germans and partly by the French, are subterranean deposits, comparable in many respects to our own deposits of rock salt, and susceptible of mining on a very large scale and by cheap methods. Some of the strata of potash salts formerly found were of large dimensions and of such a high degree of purity that the product therefrom could be ground and shipped for direct application as a fertilizer ingredient without further manipulation, thus offering a very cheap product—or else a very profitable one. This practice has been abandoned because of high transportation costs and because these high-grade strata are now largely exhausted; but the material from the lower grade can still be refined to a high-grade product by simple and inexpensive processes yielding valuable by-products, so that the situation is not materially altered.

It has been the dream of those interested in the establishment of an American potash industry that we might find in America a deposit comparable to the German ones. The first organized search for deep sources of potash, as conducted jointly by the Bureau of Soils and the Geological Survey, was a reconnoissance of the saline deposits at that time accessible for examination; its object was to see if, associated with the saline deposits, there might not be strata of potash salts or indications that such strata existed. The conditions promoting the deposition of rock salt are also favorable to the deposition of potash salts—arid con-

ditions inducing the evaporation of bodies of brines with the crystallization of the salines contained therein.

Accordingly, salt mines were entered and the exposed faces of salt strata were sampled. The brines from salt wells were analyzed, as were also those from oil wells, where such were obtainable, and mother liquors from salt refineries—all of these resulting negatively from the potash point of view. Limitations in funds confined these explorations to those salt bodies that already had been exposed by commercial exploitation. This included deposits underlying the States of New York, Pennsylvania, Ohio, Michigan, Kansas, and Louisiana. Nowhere was there found any potash in more than traces, and nowhere were there indications of associated deposits of crystallized potash. At the same time, it should be remarked, nowhere had the deposits been explored thoroughly for potash deposits. They had been examined only from the point of view of salt production. Nowhere in America have the great deposits of salines been thoroughly explored for associations of potash; and until this is done in accordance with the most advanced methods of exploration, it will not be possible to say that even the more eastern and better known deposits do not contain potash.

In Texas, however, much more promising results have been obtained. Early in 1912, through the researches of J. A. Udden, Director, Bureau of Economic Geology and Technology, of the University of Texas, potash was discovered in a brine taken from a deep boring at Spur, in Dickens County, and later in other brines from Potter, Randall, Midland, Dawson, Ward, Loving, Glasscock, Borden, Reagan, and Ector Counties. While the potash was low in concentration, the indications were that the brines contained the leachings from potash strata or from salt strata containing important concentrations of potash. In 1915, the U. S. Geological Survey entered the field with a test well at Cliffside, and since that time has continued its observation of the brines and drillings from the various oil wells put down in the region supposed to be underlain by potash-bearing strata. Numer-

ous observations of great interest and importance have been made. Not only have brines containing as high as 23 per cent of potash been obtained, but crystalline potash salts of recognized mineralogical formation, namely, polyhalite ($K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$) and sylvinite have been identified, indicating the presence of definite strata of crystallized potash.

TABLE XLII
POTASH-BEARING WELLS IN WESTERN TEXAS, 1923

| Name of Well | County | Potash in Sample, Per Cent K_2O | Potash in Soluble Salts, Per Cent K_2O | Remarks |
|---------------------------------|-----------|-----------------------------------|--|---|
| Spur | Dickens | ..... | 5.4 | Brine sample. Original potash discovery by Udden |
| Boden | Potter | ..... | 9.2 | Crystals of red salt |
| Miller | Randall | ..... | 6.1 | |
| | | | 10.5 | Salts from different depths |
| Bryant | Midland | ..... | 8.9 | |
| Burns | Dawson | 11.95 | 21.1 | Do. |
| | | 15.20 | 23.2 | |
| River | Ward | 9.03 | 14.4 | Best sample |
| Means | Loving | 11.21 | 16.1 | Do. |
| McDowell | | | | |
| No. 4 | Glasscock | 7.5 | 9.95 | Do. |
| G. A. Jones | Borden | ..... | 22.9 | Practically pure polyhalite |
| Cliffside | Potter | Traces | ..... | U. S. Geol. Survey well did not completely penetrate salt beds. |
| St. Rita group (wells 1-5, 7-9) | Reagan | 9.75 | 14.17 | Best sample |

These promising observations have been made in that part of western Texas known as the Panhandle region,

including parts of some 79 counties. For a detailed account of these investigations see the article "The Potash Field in Western Texas," by Dr. Geo. R. Mansfield,¹ and the bulletin, "Geology of a Part of Western Texas and Southeastern New Mexico, with Special Reference to Salt and Potash," by H. W. Hoots,² both of the U. S. Geological Survey.

INTERPRETATION OF OBSERVATIONS

The unsatisfactory nature of samples taken with churn-drills or rotary outfits, such as were used in the wells mentioned above, especially if the interval between the samples is greater than 5 feet, is readily apparent. The mixing of the material effectually prevents the recognition of individual beds unless they are very thick. The dangers of "salting" lower beds by material from higher levels and of misinterpretation caused by "hangover bailings" are ever present. The necessary water in the hole, by its solvent effect on salts of differing solubilities, may either enrich or impoverish the sample, and this effect is intensified if the water is in contact with the sample for any great length of time. The results are therefore to be regarded as suggestive rather than as giving any accurate idea of the number, character, and quality of the individual beds.³

Polyhalite contains on the theoretical basis 28.9 per cent potassium sulphate, 19.9 per cent magnesium sulphate, 45.2 per cent calcium sulphate and 6 per cent water. Since the calcium sulphate here present is relatively only slightly soluble in water while the other two saline ingredients are readily soluble, a water extract of this mineral, if saturated, will contain as high as 22.4 per cent actual potash, a concentration closely approached by the brines from the Jones and the Burns wells, of Dawson and Borden counties, respectively.

The potash-bearing strata of this region, according to present indications, are encountered at workable depths,

¹ J. Ind. Eng. Chem., **15**, 494 (1923). Cf. also "Potash in 1924," by G. R. Mansfield and Leona Boardman, U. S. Geol. Survey.

² Bul. **780-B**, U. S. Geol. Survey, 1925.

³ Mansfield and Boardman, "Potash in 1923," U. S. G. S.

1000–1500 feet. For their definite exploration it will be necessary to use core drills lubricated with brines of such composition that they will not dissolve the potash from the cores secured. The difficulty of obtaining adequate coöperation from commercial oil drillers and other considerations would appear to make it necessary to inaugurate systematic drilling with potash exploration as the main objective, and the expense and uncertainty attending this would seem to make it imperative that governmental financing be adopted. Only by the sheerest accident, in all probability, can potash be located otherwise. The great commercial value and national importance of the discovery of workable deposits of potash would amply justify the expenditure.

ECONOMIC CONSIDERATIONS

Unfortunately, the supposed potash deposits of Texas are far removed from the present centers of general fertilizer application, and the cost of obtaining potash therefrom to be used in these regions would have to include heavy expense for transportation. Also, high wages for labor would add a differential prejudicial to successful competition with European potash at present prices. It would appear to be certainly true that Texas potash would meet with severe competition with the European commodity in the regions of the southeast where the bulk of fertilizers are now used.

However, these considerations must not be permitted to prevail as arguments against the immediate exploration of those deposits. It is not certain that transportation costs will remain at their present levels, and it will certainly come to pass that the use of fertilizer as an essential part of good agricultural practice will extend westward and eventually will cover the vast agricultural regions of the southwest which lie contiguous to the Texas deposits.

The suggestion has been made that if workable beds of polyhalite should be found in Texas, their economic importance would be offset by the low potash content of that

mineral. The validity of this argument is open to question, as no effort would probably be made to market the crude product as mined, outside of a local territory limited by considerations of transportation costs. Concentration methods applied to this material would doubtless yield high-grade potash mixtures and possibly by-products, the former greatly broadening the market to be served and the latter enhancing the prospects of profits.

ENLARGED DEMANDS FOR AGRICULTURAL POTASH

The use of fertilizers must be regarded as economically important in two respects: as a conservation measure, to restore to the soil the plant foods removed with the harvested crops; and as a labor-saving device, to enable the farmer to raise more produce per given amount of labor. The amount of cultivation being the same for a poor crop as for a good one, if the use of fertilizer results in a good crop where otherwise only a poor one would be obtained, it is obvious that the yield per unit quantity of labor has been increased. The use of fertilizer, therefore, increases the efficiency of the man on the farm. It releases labor from the farm to other industries. To disparage the use of fertilizer in the great agricultural regions of the Middle West, on the basis that the soils are rich and the yields are good enough without it, is therefore as wise as disparaging on the same basis the use of any other labor-saving device. The question is not, "Can one raise good crops without fertilizer?" but rather, "Can one raise better crops with fertilizer, and if so does the investment in fertilizer yield a profit in soil conservation, increased crop yields, and the saving of labor?" On this basis, and on this basis alone, will the geographical limitations of fertilizer use be imposed.

When such considerations prevail, the regions of general fertilizer application will not be centered in the Southeast as at present, but will cover the active agricultural areas of

the Middle West and the Southwest. At such a time Texas potash would be the most available and would enjoy a preferential market over the European commodity. Thus the market in part will be brought to the source of supply and will be removed from regions in which the European commodity can compete.

The agricultural use of potash is associated at present particularly with certain soil types and certain crops, although it is without definite restrictions with respect to either. Potash is more widely applied to crops grown on gray soils, typified by the light sandy soils found in the Southeast and extending northwestward as far as Ohio. On these soils, particularly in the raising of cotton, it is regarded as an essential—and correctly so. During the war years of potash scarcity, there were observed, in efforts to raise crops without potash applications, some very unfavorable conditions in the growing crops, which were interpreted as evidence of potash starvation. On these soils potash gives very marked results, and that too, on crops other than cotton. The bulk of the cotton crop being grown on these soils, the use of potash has become particularly associated therewith and cotton has been listed accordingly as a crop requiring heavy applications of potash. Potatoes and tobacco are likewise found on this list, not so much because of any peculiar demands made on the soil for potash, but rather because the use of potash in the growing of those crops by intensive methods has been found to be highly profitable. A like experience would undoubtedly be had in the intensive cultivation of any other crop. However, the great staple crops are not yet raised by intensive methods.

The use of fertilizer is a prerequisite of intensive agriculture, and will increase as intensive agriculture becomes more generally employed. At such a time it will be found that the beneficial results of potash applications will be obtainable without regard to the crop or the soil on which it is grown. Sufficient experimental data are already at hand to justify such an expectation. Factors exerting a limiting

influence on the agricultural use of potash are therefore hard to find.

It has been shown that by-product potash is potentially capable of meeting, in large part, present American demands. Will there be a conflict between these two potash enterprises, by-product potash and Texas potash? In answer it may be said that if by-product potash can compete with the European commodity it can certainly compete with that from Texas in the present regions of heavy fertilizer application. An import tariff would be an expedient of more benefit to the former than the latter. At the same time, a local market developed in the Southwest, which would promote the successful economic exploitation of the Texas deposits, would possibly be too remote to be readily and favorably accessible to by-product potash yielded from the industries now more largely concentrated in the East. The market, it would appear, would automatically divide itself between the two sources and would become adjusted to both without detriment to either.

POTASH AND CONCENTRATED FERTILIZERS

In the consideration of methods of extracting potash from new raw materials or of new methods of extracting it from old raw materials, some emphasis should be placed on the consideration of the form in which the potash is to be yielded, particularly with a view to its easy application to the manufacture of concentrated fertilizers.

These fertilizers are high-grade chemical compounds, as contrasted with the miscellaneous assortment of low-grade chemical and waste products which constituted the low-analysis fertilizers of the past. In the concentrated product, fertilizer ingredients, or elements of plant food value, make up the entire compound instead of only a part of it, entering into both acid and basic radicals. Concentrated fertilizers are suitable mixtures of potassium and ammonium phosphates and nitrates. The potash is accordingly present

as phosphate or nitrate; and potash intended for use in this new fertilizer development should be as phosphate or nitrate or in a form readily convertible into these salts.

However, for the manufacture of potassium phosphate, the present potassium chloride of commerce can be employed. By treating it with phosphoric acid, hydrochloric acid is obtained as a by-product; or, conversely, in the manufacture of hydrochloric acid, potassium chloride may be substituted for sodium chloride and phosphoric for sulphuric acid, and a valuable product, potassium phosphate, yielded instead of sodium sulphate, the product of the present process. This reaction does not require elevated temperatures, and its technique, now completely worked out, does not appear to offer any difficulties.

The production of by-product hydrochloric acid as outlined may represent such economies as to make this the preferred method of preparing that acid. But in case such a by-product is not desired, it would be advantageous to have the potash in such a combination that it could be used to neutralize phosphoric acid or to absorb nitric acid without the liberation of a corrosive acid. For such a purpose, potash as carbonate is ideal. But an even greater advantage would be gained if the new process yielded the potash directly as nitrate or phosphate. The great advantage of concentrated over dilute fertilizers being the saving in transportation and handling charges per unit quantity of plant food, this advantage in such a case would accrue to the potash manufacturer. At any rate a premium will accrue to potash offered in any of those forms facilitating subsequent processing, and this advantage should be constantly kept in mind.

It appears a certain outcome of investigations now under way in the Bureau of Soils that phosphoric acid will become an available industrial reagent, and that in fertilizer manufacture it may be able to take the place of phosphate rock and sulphuric acid, to a certain extent, where that substitution is found desirable; and many advantages will accrue from the substitution. The new program of fertilizer man-

ufacture, as originated within that Bureau and as given wide publicity in the Muscle Shoals discussions as the basis of several plans for fertilizer manufacture there proposed, will be applied particularly to provide for the growth within the fertilizer industry and to supply regions at a distance from present points of production. In planning for American potash production, therefore, one may well contemplate that eventuality and provide potash in a form which will make it particularly adaptable for use in connection with, and as a part of, that development.

CONCENTRATED POTASH

In this connection it might be well to point out the advantages to be realized from the manufacture of concentrated potash as contrasted with the dilute article which in the past has had ready acceptance in the fertilizer industry. Formerly, German kainite, containing only 12 per cent actual potash, constituted the bulk of imported potash, and accordingly the bulk of that constituent entering mixed fertilizers. It therefore became the lower standard, and any potash carrier containing that percentage was regarded as acceptable for fertilizer use, other things being equal. Kainite delivered on the Atlantic seaboard enjoyed the very low freight rate accorded it by the Government-controlled German merchant marine, so that consideration of freight charges did not enter in as a serious matter.

When potash came to be produced at inland points, however, requiring rail shipment to points of utilization, transportation charges became an important item. This has been further accentuated by the advance in freight charges imposed since the War. At present, therefore, the concentration in which potash is offered may be the factor which will determine whether or not it can enter the market in competition with the imported article. The freight rate to market is now a most important consideration, potash being

the finished fertilizer and constitute a leading argument in favor of the substitution of high-analysis and even concentrated fertilizers for the present dilute products, and will eventually force their general adoption. High-analysis mixtures (within limits) cannot be manufactured from low-analysis ingredients. In the past, with only low-analysis ingredients available for fertilizer manufacture, low-analysis mixtures were the only products possible to the fertilizer manufacturer. Now, with a change in the demand has come a change in the grade of the ingredients offered on the market. Agricultural potash, to compete in this market, must accordingly be high-analysis potash.

A large export business is now carried on in American phosphate rock. For a foreign destination the rock must be concentrated in order that transportation charges may not be excessive. This entails added costs and increased losses at the mines. At best, 35 per cent phosphoric acid is all that is obtainable by concentration methods.

For export purposes a great advantage would accrue if the phosphoric acid of this rock were separated and neutralized with potash or ammonia and shipped as potassium or ammonium phosphate.

Formerly Germany was a large purchaser of American phosphate. As that nation now exports both potash and ammonia, she would not be interested favorably in their importation unless other advantages outweighed this consideration. But this would not apply to the other nations that import all three of these commodities.

America is now exporting both phosphoric acid and ammonia, each carrying with it a heavy burden of material for which no returns are obtained. When phosphoric acid and ammonia are combined, all of this material is eliminated. At present, America is the only nation in a position to offer this combined product. Each of these materials, when produced in combination with the other, should occupy a more favorable position in the world market than it could otherwise attain.

POTASH IN OTHER INDUSTRIES

Potash is preëminently a fertilizer commodity and is of prime importance to the fertilizer industry. Therefore the potash industry is closely allied to agriculture, by virtue of the fact that 90 per cent of the potash entering the American market is consumed in agricultural operations. However, the remaining 10 per cent does not suffer in comparison in point of importance, since it enters industries where it is likewise a necessity and becomes a part of products in widespread use, affecting the lives of the people in general. It is just as essential that an assured source of potash be provided for those industries as for agriculture. The industrial uses of potash are in accordance with well-known and standard procedures and therefore need no elaboration here. To name them will be sufficient.

As a military necessity and a commodity pertaining to national defense, potash is of great importance as it is extensively used in the manufacture of shrapnel powder, hand grenades, primers, fuses, and pyrotechnic devices. It is regarded as an essential in such preparations and also in the manufacture of slow-acting black powder, which is always in demand for certain uses.

In the manufacture of the modern match, potash in the form of the chlorate is in general use, as it is the oxidizing agent best adapted to that purpose. There are few to whom potash, as a constituent of the safe and convenient modern match, is not of daily benefit. Likewise as an ingredient of the liquid soaps and of some of the finer soaps intended for special purposes, it finds an important and useful application.

Potash is likewise regarded as an essential constituent of the finer grades of glass prepared for special purposes, such as the manufacture of lenses for optical instruments, cut glass, electric light bulbs, and other uses where the particular properties of a potash glass contribute greatly to the ends sought.

These are but a few of the many industries in which potash as a reagent plays an essential rôle. The small tonnage annually consumed in these industries, as compared with that used in agriculture, would appear to be a guarantee against a shortage, even in the greatest emergency; yet during the late war a serious handicap was placed on all these industries by their inability to obtain even the relatively small amount of potash on which they depended. Even the chemist in his laboratory was exhorted to substitute other compounds for potash wherever it was possible to do so. This was an experience which impressed a lesson not soon to be forgotten!

SUMMARY—TOTAL QUANTITIES OF AMERICAN POTASH AVAILABLE

We have in sight the early and successful solution of our potash problem. From industrial wastes, in industries already operating on a successful basis, wherein through the installation of more economical methods by-products can be developed, we may hope to recover a large portion of our present and future potash requirements. Reference is made to the blast-furnace, the cement, the sugar, and the alcohol industries. Surveys of these sources have been completed and the quantities of potash which can be yielded as by-products have been determined. The feasibility of its recovery has been demonstrated; but there remains the task of perfecting the methods employed, and bringing about improvements in processes which will make the recovery of potash so attractive economically that the industries concerned will be impelled to practice it. The author feels that these problems are near solution and that this solution is almost within our grasp. He believes that a short period of aggressive chemical and engineering research will remove the remaining difficulties and demonstrate the substantial profits which, he feels confident, can be realized from the recovery of this potash. War-time momentum has been

largely lost, but there yet remains in important quarters a very great interest in this problem which can be, and is being, utilized to further the enterprise.

What the author has in mind may be illustrated by an analogous conservation which makes available for American agriculture great quantities of that other essential of present fertilizer practice, namely ammonium sulphate. This is a by-product of the coking industry. Its value has now become so well recognized and its production so well standardized that the coking of coal without by-products has almost disappeared, and the production of by-product ammonia has advanced from nothing to a yearly output of almost 600,000 tons. What has happened in the coking industry the author hopes to see duplicated in the blast-furnace, the cement, the sugar, and the distillery industries. The important results already obtained in governmental and private researches convince him that this is an entirely reasonable expectation.

In the following table are summarized the quantities of by-product potash potentially available for American agriculture from these industries:

TABLE XLIII

POTASH POTENTIALLY AVAILABLE AS AN ANNUAL BY-PRODUCT OF AMERICAN INDUSTRIES

| Industry | Available Quantity in Tons K_2O | |
|--------------------|--------------------------------------|-----------|
| | Present | Potential |
| Blast-furnace..... | 83,700 | 200,000 |
| Cement..... | 85,000 | 189,000 |
| Borax..... | 40,000 | 60,000 |
| Alcohol..... | 32,000 | 140,000 |
| Sugar..... | 7,000 | 16,000 |
| Total..... | 247,700 | 605,000 |

In various mineral deposits already surveyed there are additional quantities of potash, enormous in extent and practically inexhaustible, but unavailable at present and likely to remain so until further research has determined more profitable methods of recovery. The greensands of New Jersey, Delaware, and Maryland, the potash shales of Georgia, the leucites of Wyoming, the alunites of Utah and the potash feldspar of many States in the aggregate contain inexhaustible quantities of potash, and the problem of recovering it therefrom is now much nearer solution than is generally recognized. The problem is one of by-products, other values to be recovered with the potash to lower its cost of manufacture. These are now being developed. Results now in hand warrant the expectation that all of these materials will be placed under exploitation to yield important quantities of agricultural potash and other useful products. Here is potash in quantities sufficient for the present needs of American agriculture and for the greatly increased needs of the future, for an indefinite period of time. It seems an entirely reasonable expectation that American chemical ingenuity will be equal to the task of recovering it efficiently and profitably.

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